US012261073B2

(12) United States Patent
Long

(10) **Patent No.: US 12,261,073 B2**
(45) **Date of Patent: *Mar. 25, 2025**

(54) **ELECTROSTATIC CHUCK ASSEMBLY FOR PLASMA PROCESSING APPARATUS**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **18/654,429**

(22) Filed: **May 3, 2024**

(65) **Prior Publication Data**

US 2024/0282614 A1 Aug. 22, 2024

Related U.S. Application Data

(63) Continuation of application No. 17/551,247, filed on Dec. 15, 2021, now Pat. No. 12,002,701.

(60) Provisional application No. 63/194,529, filed on May 28, 2021, provisional application No. 63/194,256, filed on May 28, 2021, provisional application No.
(Continued)

(51) **Int. Cl.**

H01L 21/68	(2006.01)
H01J 37/32	(2006.01)
H01L 21/683	(2006.01)

(52) **U.S. Cl.**
CPC ***H01L 21/6833*** (2013.01); ***H01J 37/32082*** (2013.01); ***H01J 37/32577*** (2013.01); ***H01J 37/32724*** (2013.01)

(58) **Field of Classification Search**
CPC H01L 21/683; H01L 21/6833; H01J 37/32082; H01J 37/32577; H01J 37/32724
See application file for complete search history.

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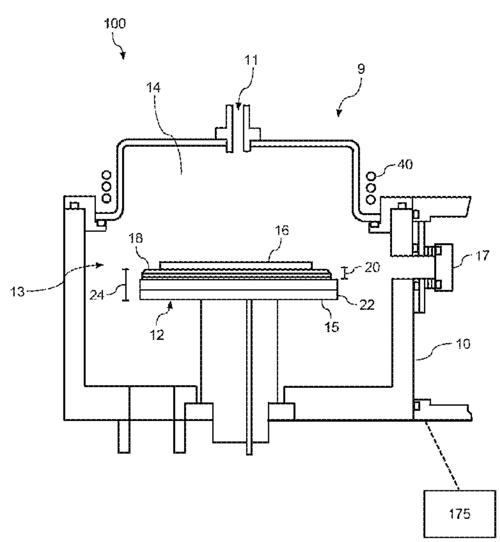
(57) **ABSTRACT**

An electrostatic chuck including a workpiece support surface, clamping layer, heating layer, thermal control system, and sealing band is disclosed. The sealing band surrounds an outer perimeter of the electrostatic chuck including at least a portion of the workpiece surface. The sealing band has a width greater than about 3 millimeters (mm) up to about 10 mm. Plasma processing apparatuses and systems incorporating the electrostatic chuck are also provided.

20 Claims, 15 Drawing Sheets



Related U.S. Application Data

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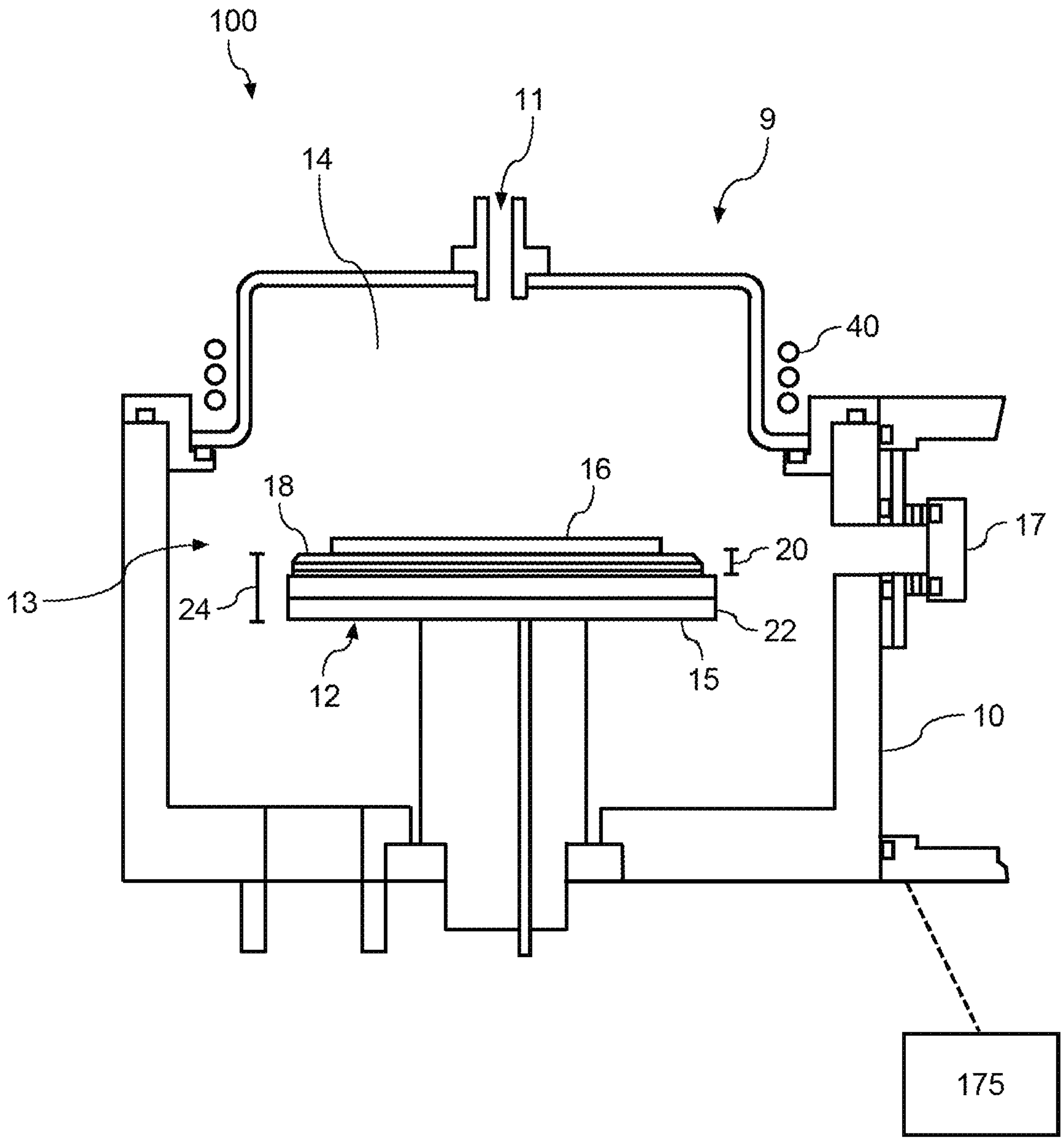
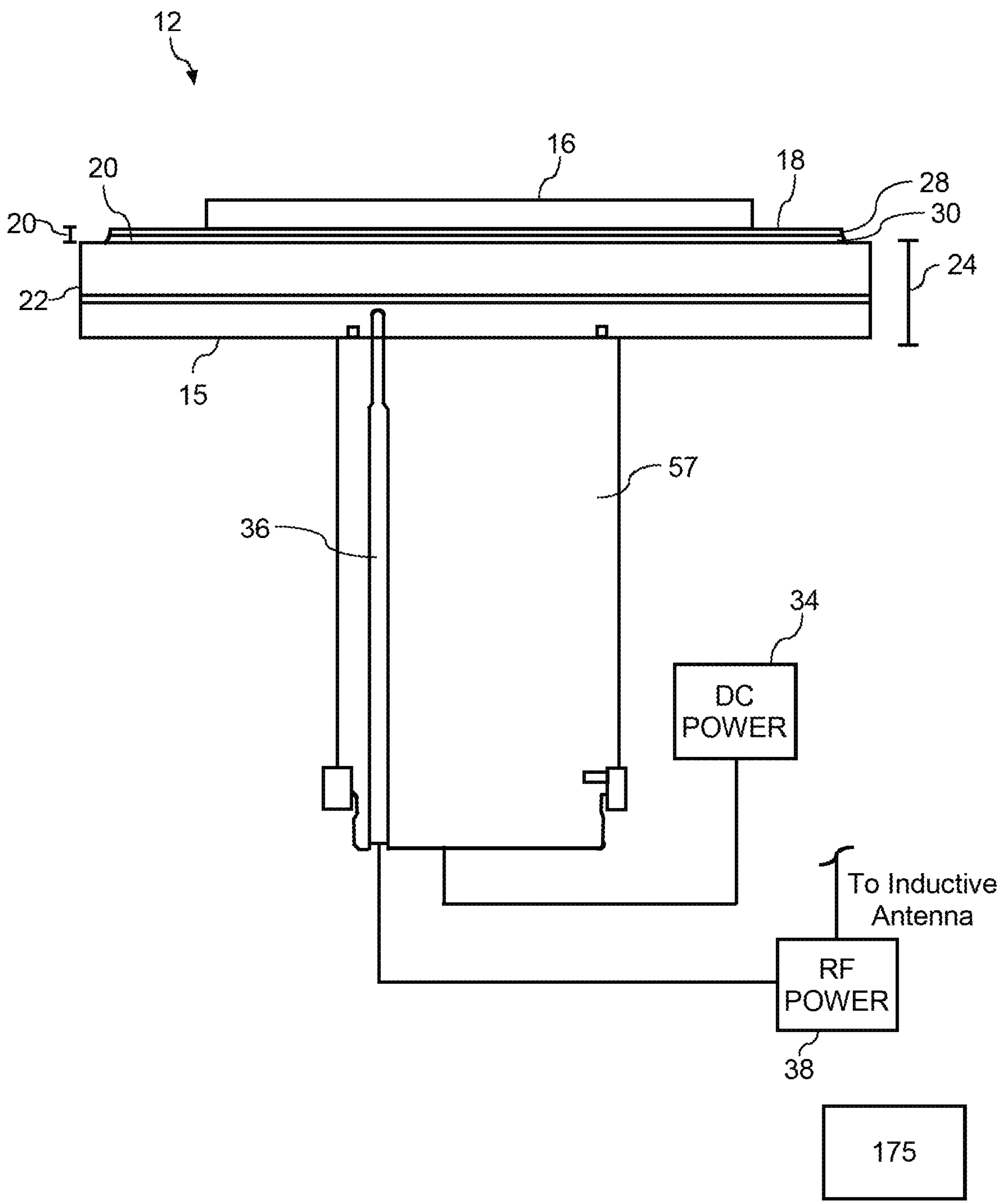


FIG. 1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DC POWER
To Inductive Antenna
RF POWER
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FIG. 2

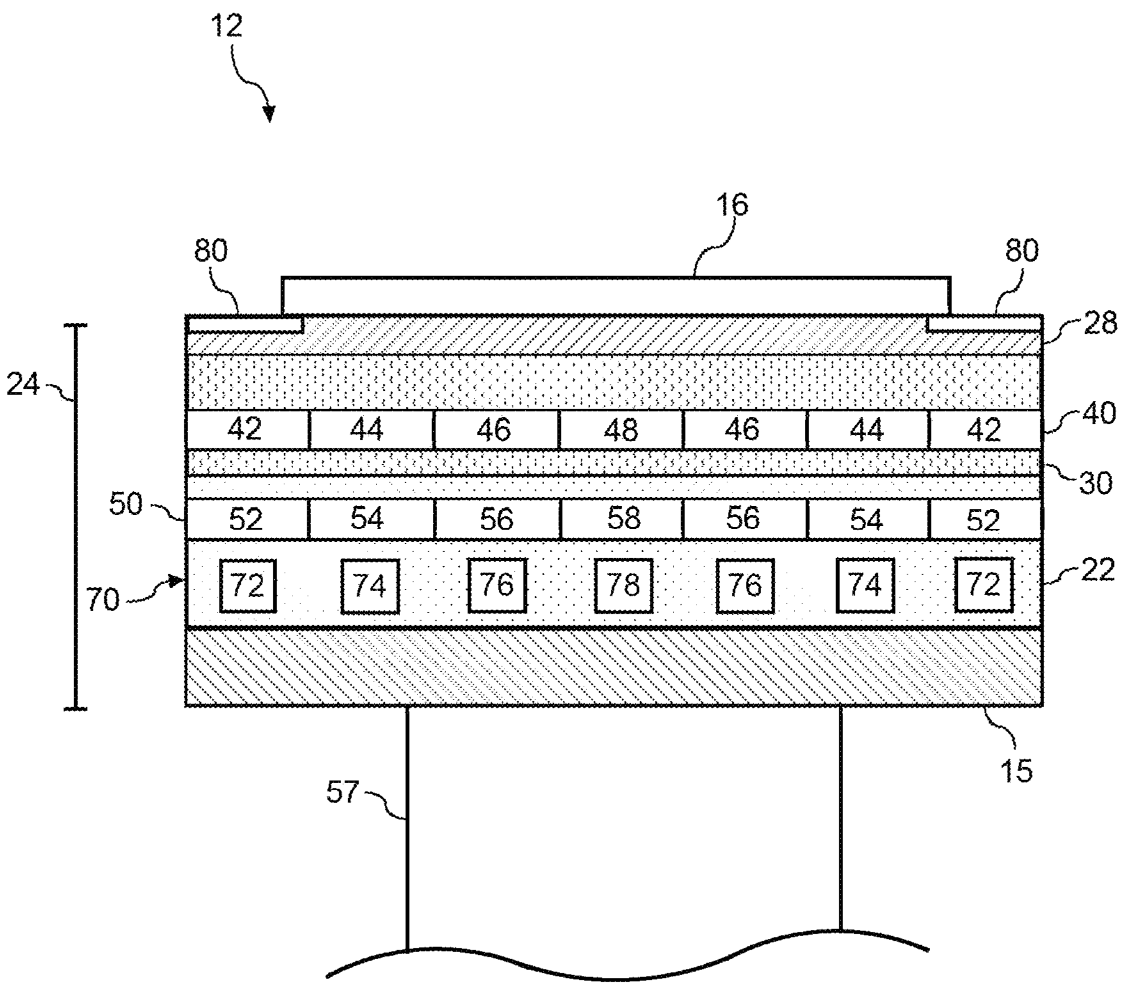
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FIG. 3

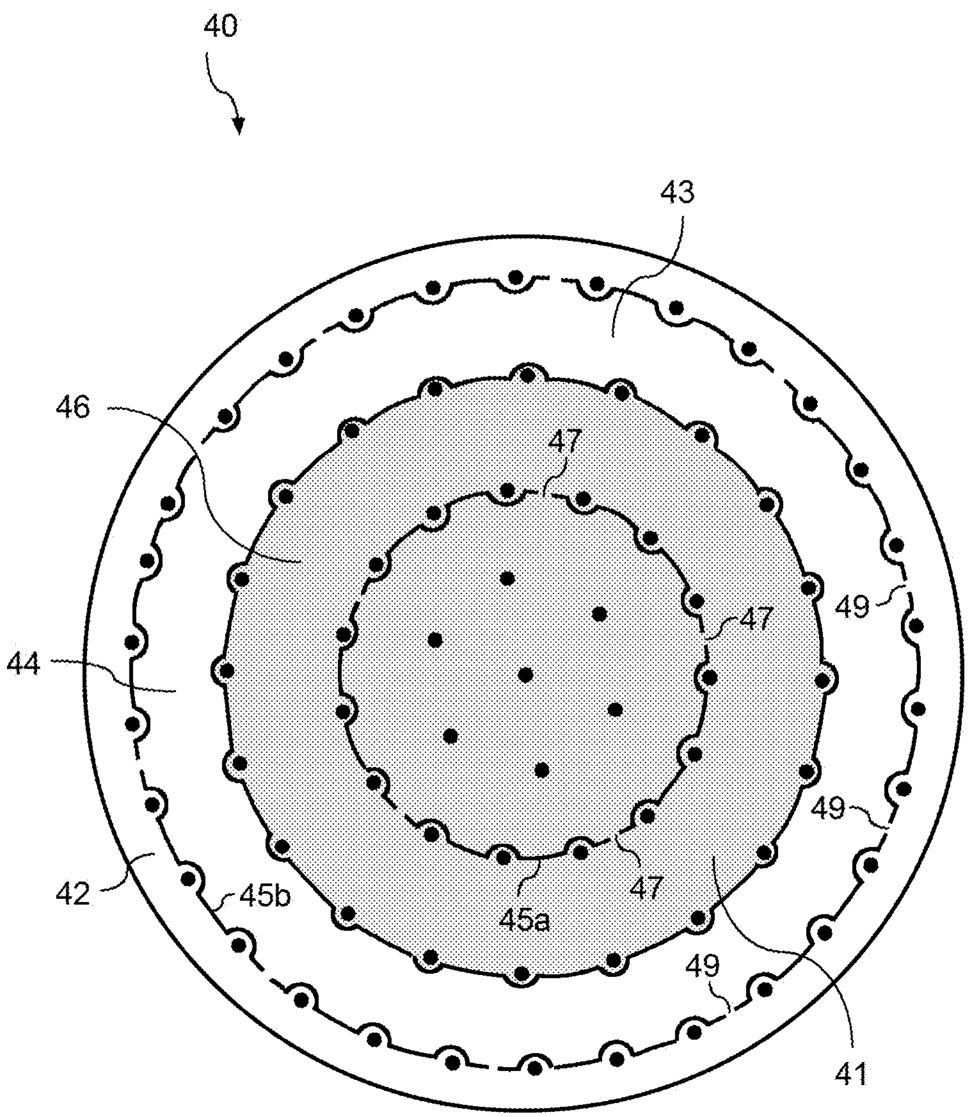

FIG. 4

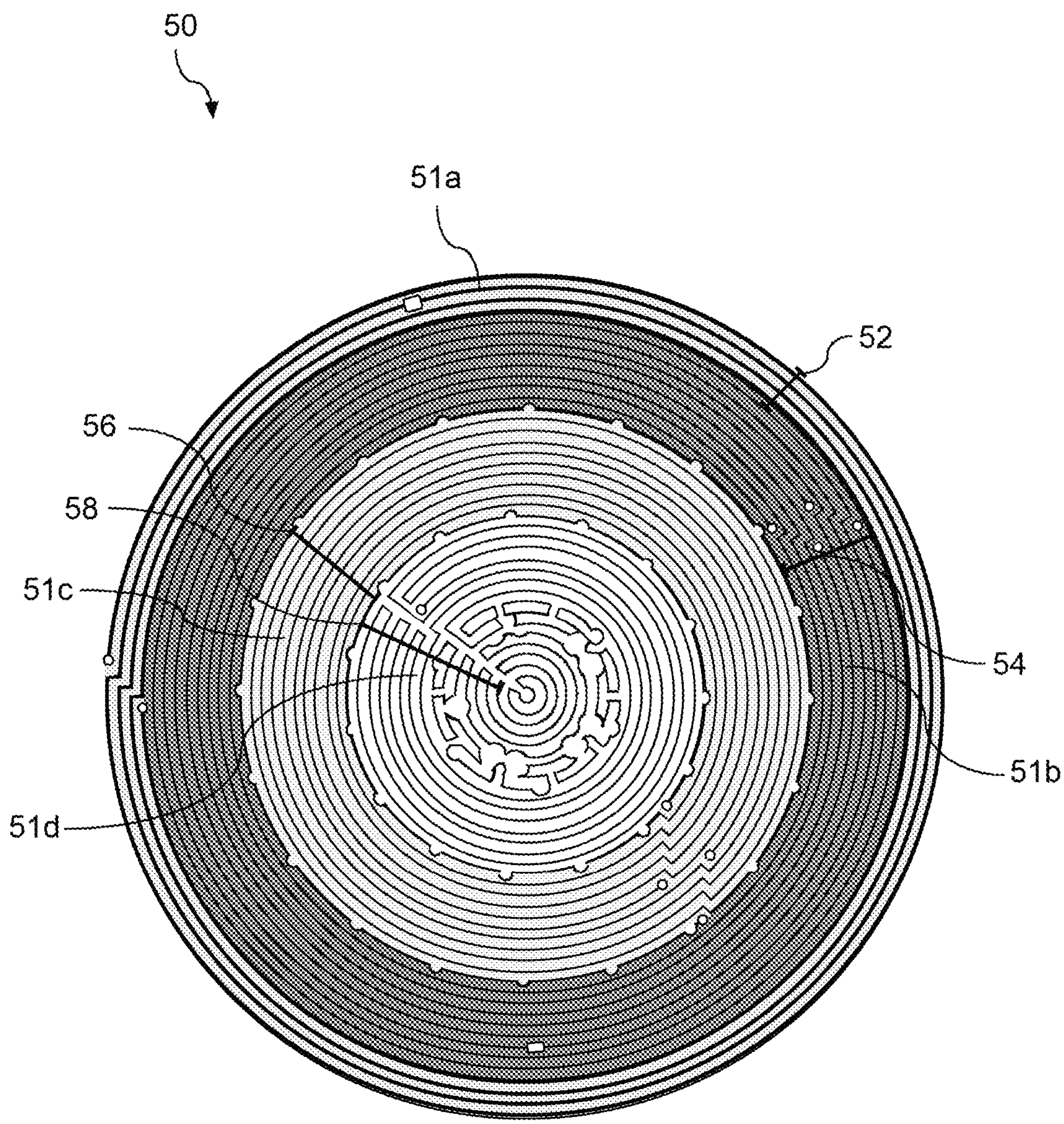

FIG. 5

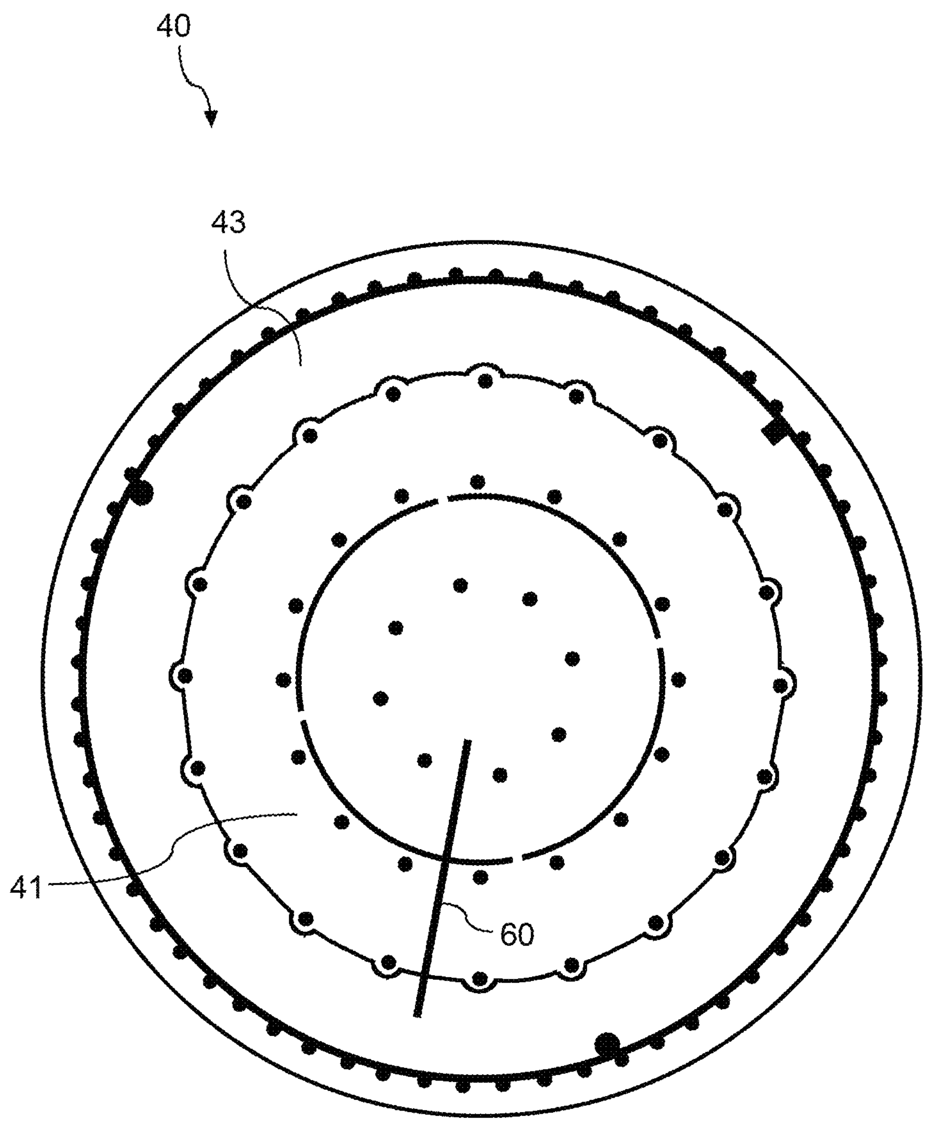

FIG. 6

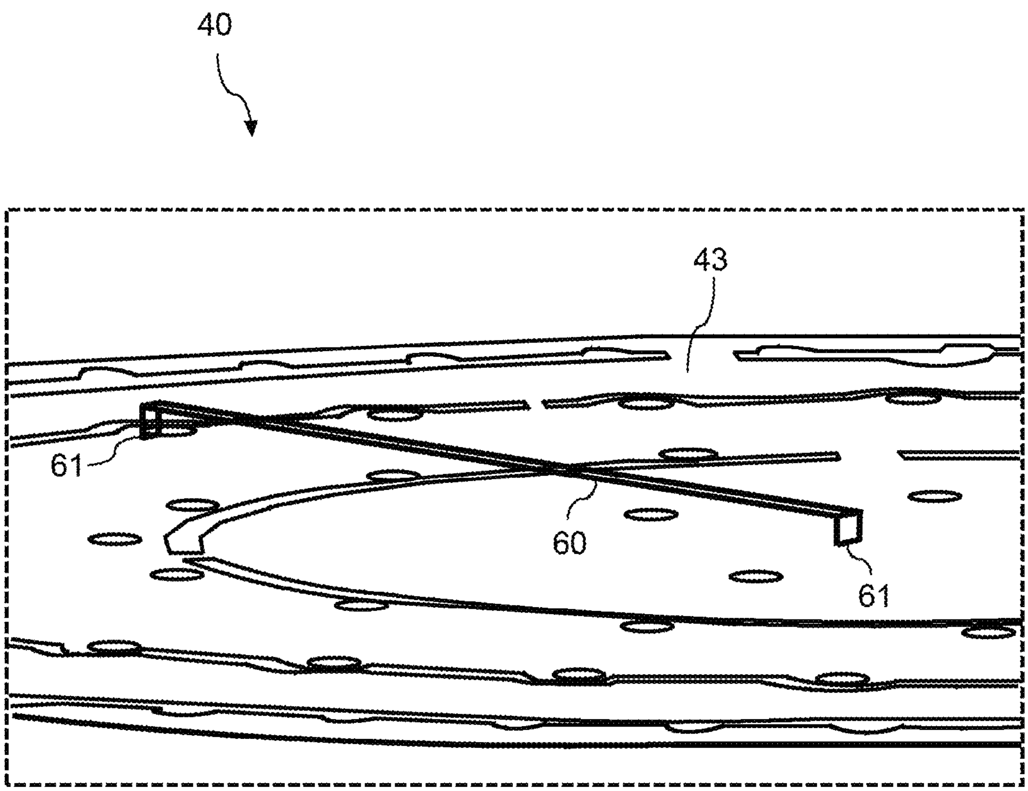

FIG. 7

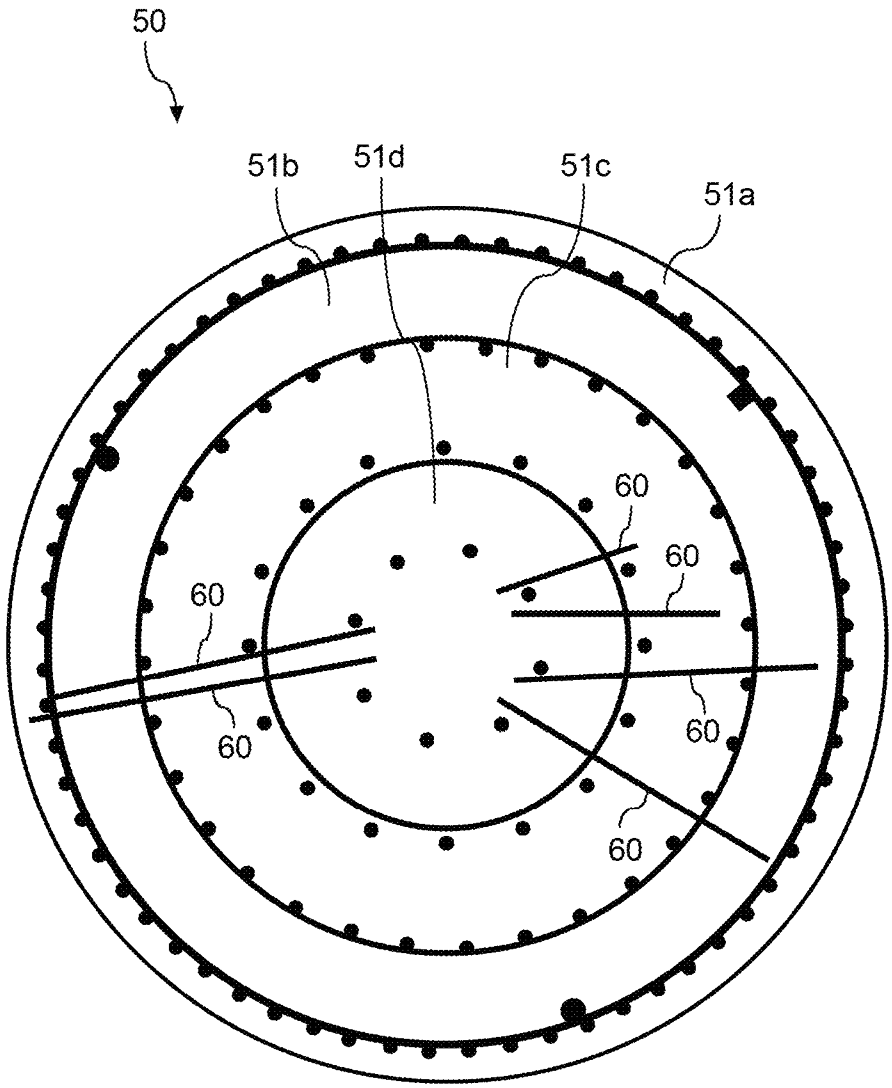

FIG. 8

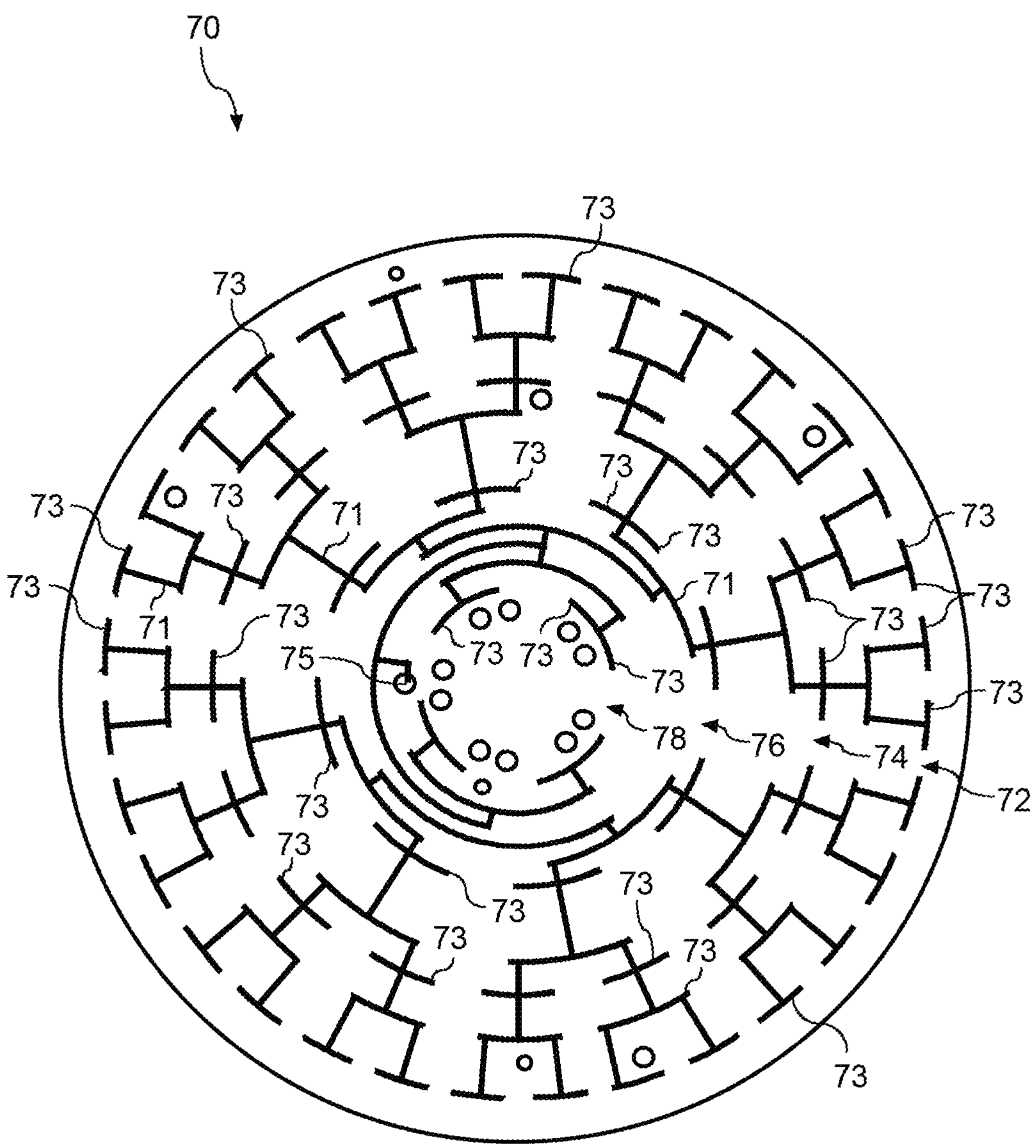
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FIG. 9

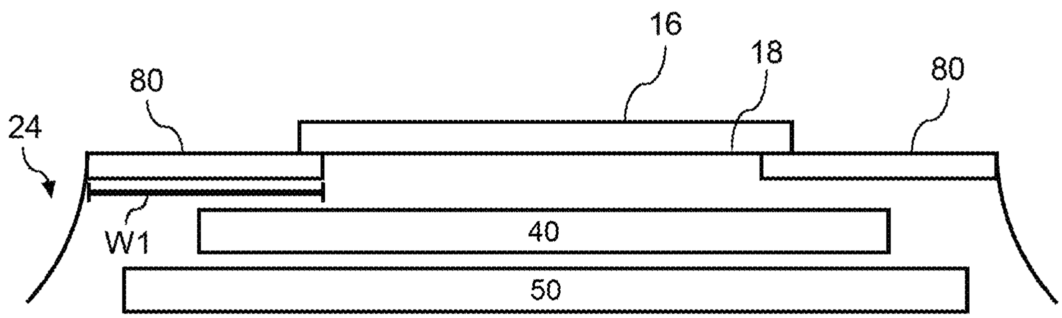


FIG. 10

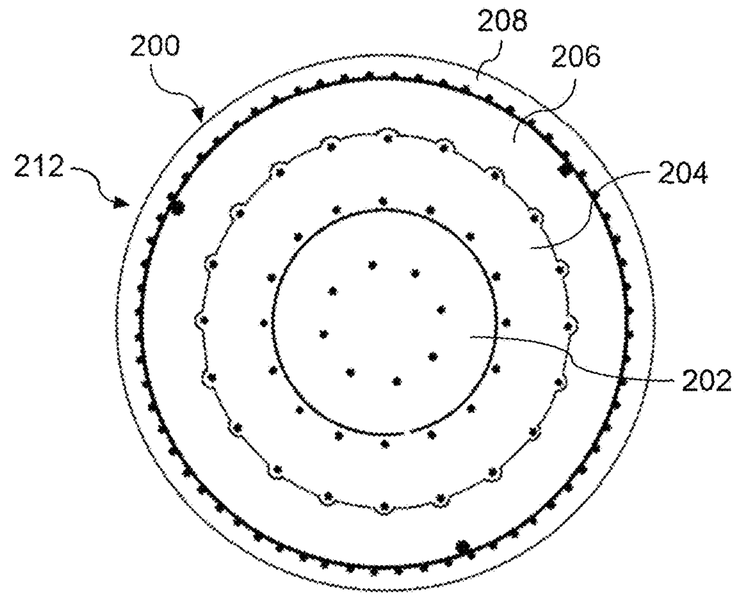


FIG. 11

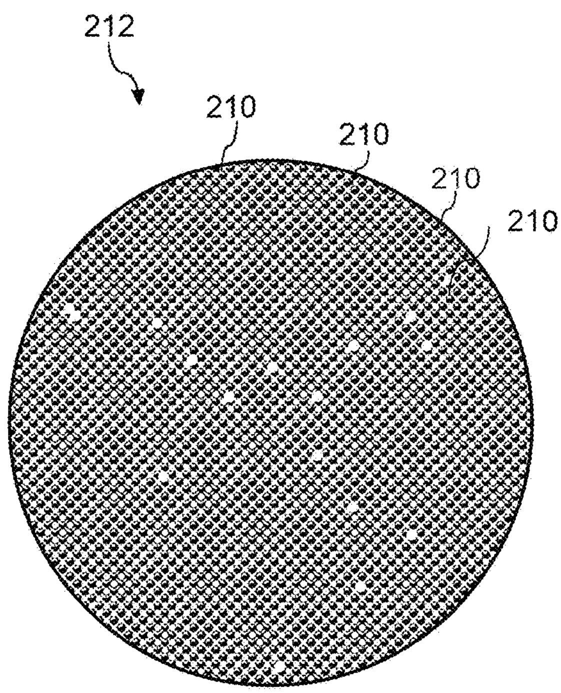


FIG. 12

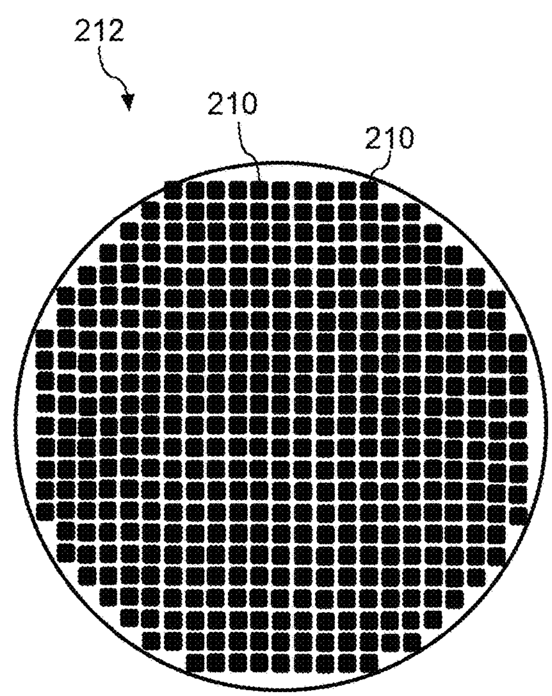


FIG. 13

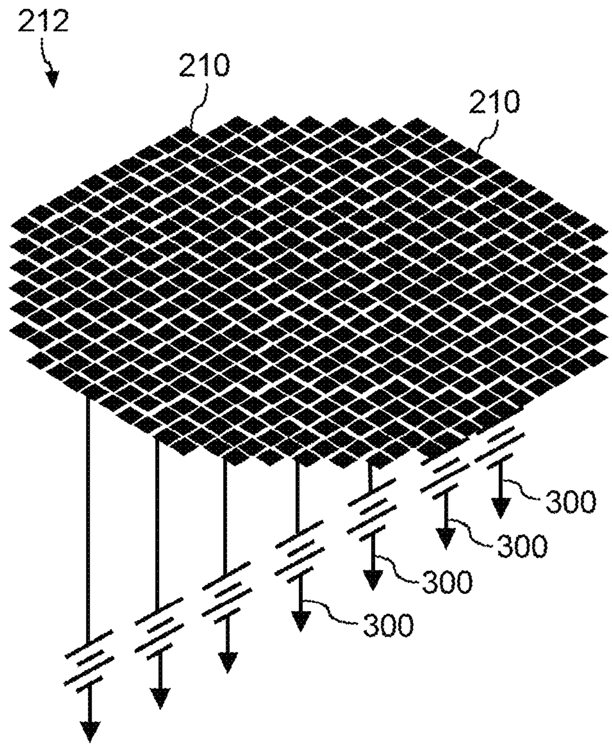


FIG. 14

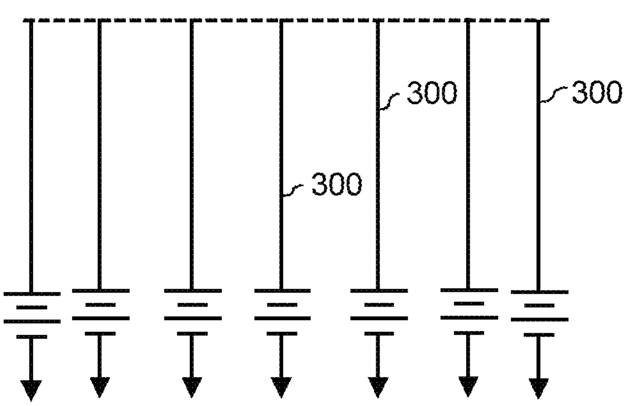


FIG. 15

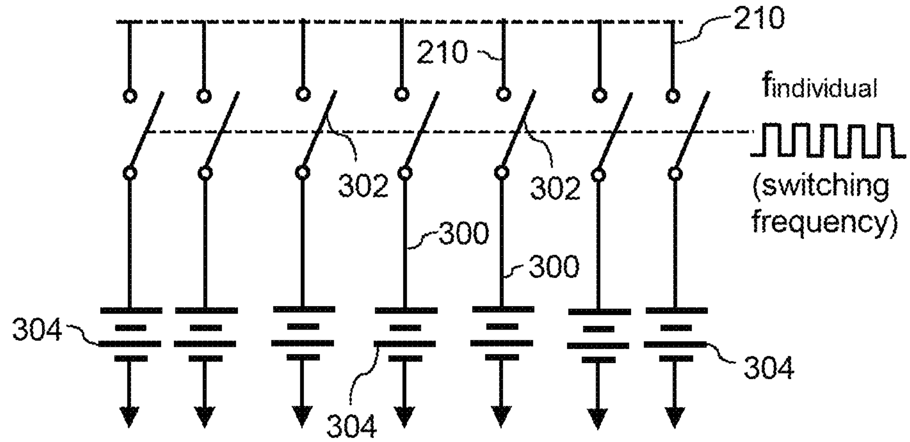


FIG. 16

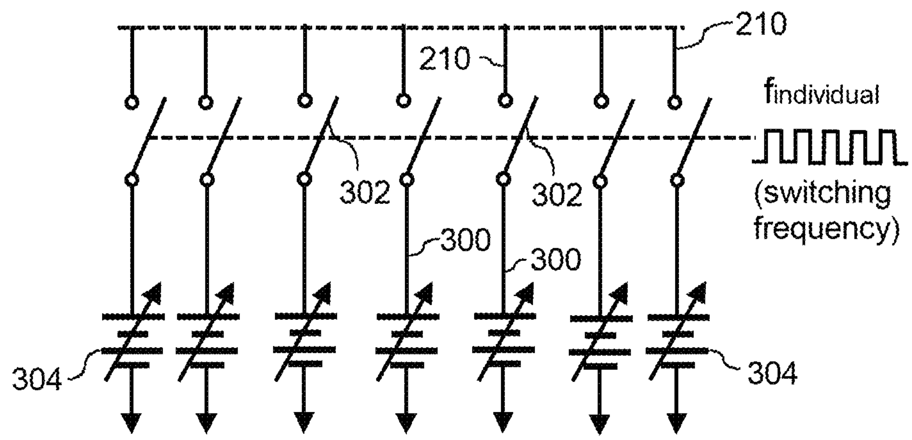


FIG. 17

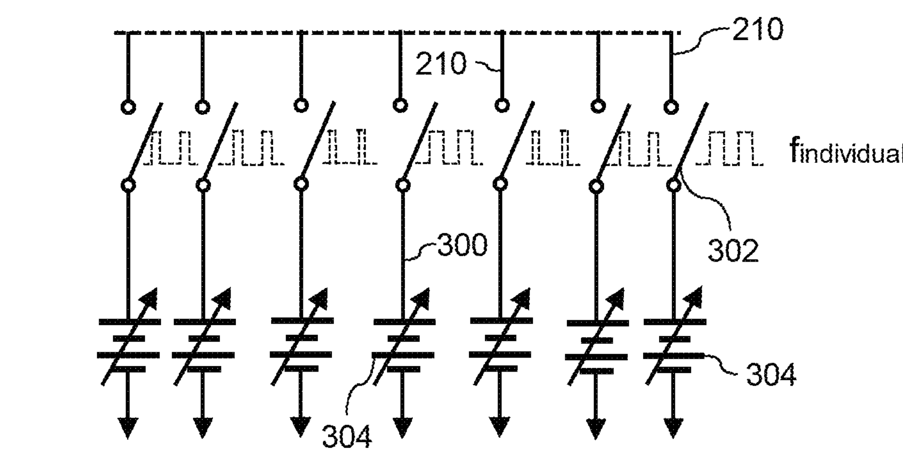


FIG. 18

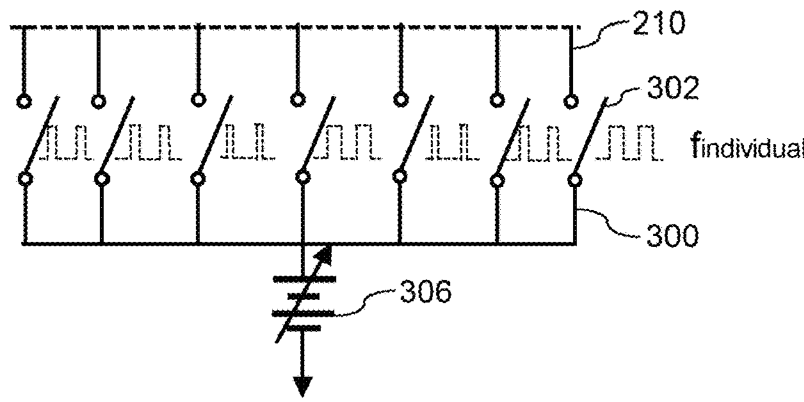


FIG. 19

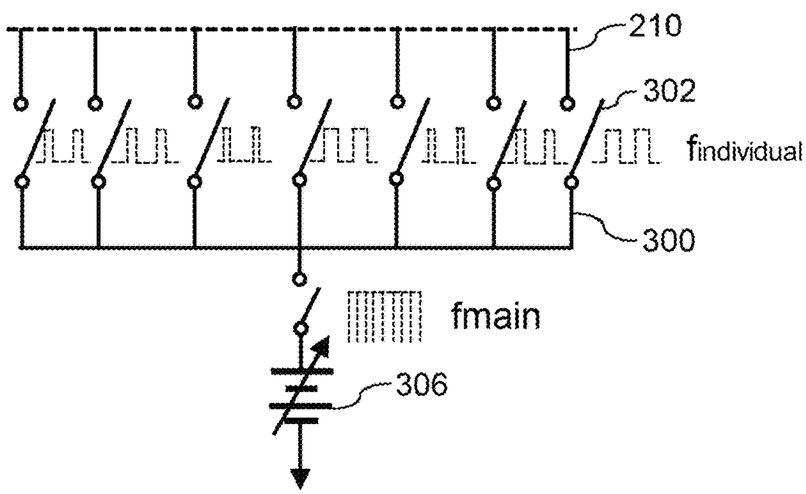


FIG. 20

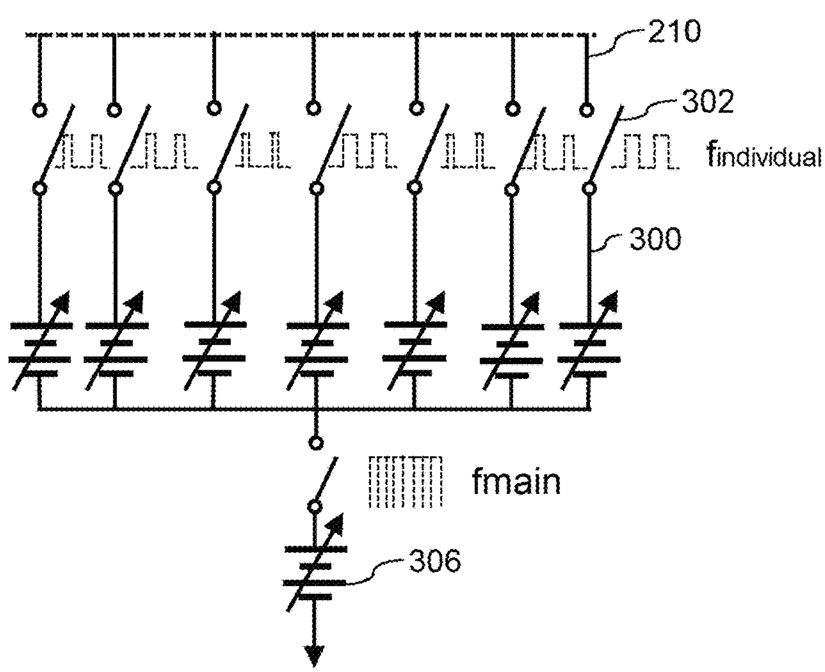
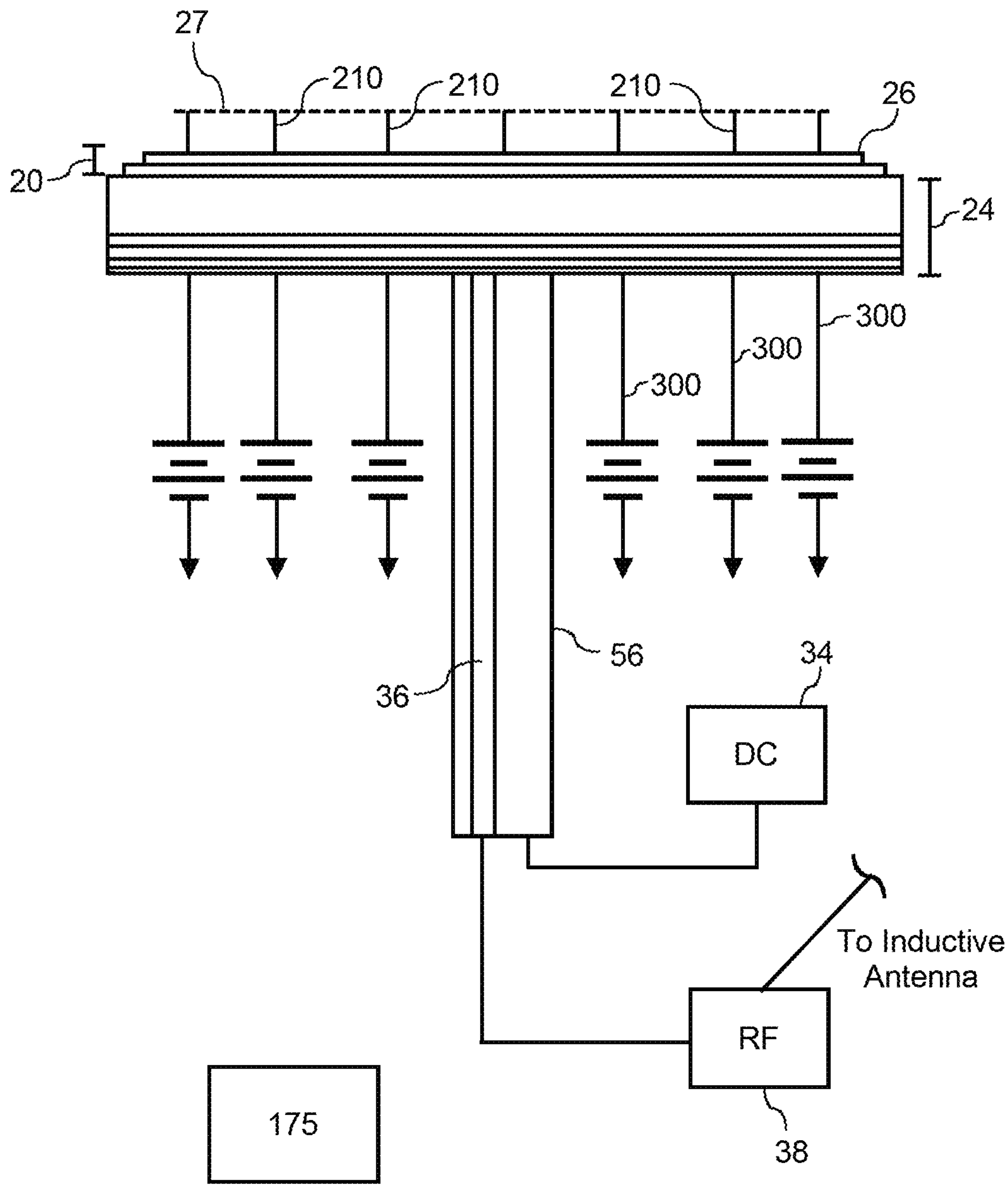


FIG. 21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56
36
34
DC
To Inductive Antenna
RF
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FIG. 22

ELECTROSTATIC CHUCK ASSEMBLY FOR PLASMA PROCESSING APPARATUS

PRIORITY CLAIM

The present application is continuation of U.S. patent application Ser. No. 17/551,247, filed Dec. 15, 2021, which claims the benefit of priority of U.S. Provisional Patent Application Ser. No. 63/131,440, titled "Multizone Electrostatic Chuck for Processing Apparatus," filed on Dec. 29, 2020, and U.S. Provisional Patent Application Ser. No. 63/131,448, titled "Multipolar Electrostatic Chuck," filed on Dec. 29, 2020, and U.S. Provisional Patent Application Ser. No. 63/194,256, titled "Electrostatic Chuck Assembly for Plasma Processing Apparatus," filed on May 28, 2021, and U.S. Provisional Patent Application Ser. No. 63/194,529, titled "Electrostatic Chuck Assembly for Plasma Processing Apparatus," filed on May 28, 2021, all of which are incorporated herein by reference.

FIELD

The present disclosure relates generally to a plasma processing apparatus for plasma processing of a workpiece. More specifically, the present disclosure is directed to an electrostatic chuck assembly for the plasma processing apparatus.

BACKGROUND

Various types of process chambers are available for processing different types of workpieces. The workpieces may comprise, for instance, glass plates, films, ribbons, solar panels, mirrors, liquid crystal displays, semiconductor wafers, and the like. Many different types of process chambers are available, for instance, for processing semiconductor wafers during the manufacture of integrated circuit chips. The process chambers may be used to anneal the wafers, carry out chemical vapor deposition, physical vapor deposition, plasma and chemical etching processes, thermal processes, surface engineering and other processes. These types of process chambers typically contain a workpiece support for holding the workpiece within the chamber.

In many processes, it is desirable to control certain parameters of the workpiece during processing in order to control uniformity during processing. Although various attempts have been made to design workpiece supports that can control temperature non-uniformities, various deficiencies and drawbacks remain. Accordingly, improved workpiece supports and plasma processing apparatuses and systems are needed.

BRIEF DESCRIPTION OF THE DRAWINGS

Detailed discussion of embodiments directed to one of ordinary skill in the art are set forth in the specification, which makes reference to the appended figures, in which:

FIG. **1** depicts an example processing apparatus according to example embodiments of the present disclosure.

FIG. **2** depicts an example workpiece support according to example embodiments of the present disclosure.

FIG. **3** depicts an example workpiece support according to example embodiments of the present disclosure.

FIG. **4** depicts a top down view of a clamping layer having two clamping electrodes according to example embodiments of the present disclosure.

FIG. **5** depicts a top down view of a heating layer having one or more heating electrodes according to example embodiments of the present disclosure.

FIG. **6** depicts a bottom view of a clamping layer and a trace connection according to example embodiments of the present disclosure.

FIG. **7** depicts a bottom view of a clamping layer and a trace connection according to example embodiments of the present disclosure.

FIG. **8** depicts a bottom view of a clamping layer and a trace connection according to example embodiments of the present disclosure.

FIG. **9** depicts a top down view of a thermal control system according to example embodiments of the present disclosure.

FIG. **10** depicts a portion of a workpiece support according to example embodiments of the present disclosure.

FIG. **11** depicts a top-down view of a clamping layer having a plurality of clamping electrodes according to example embodiments of the present disclosure.

FIG. **12** depicts a top-down view of a clamping layer having a plurality of clamping electrodes according to example embodiments of the present disclosure.

FIG. **13** depicts a schematic of electrical connections and a plurality of clamping electrodes according to example embodiments of the present disclosure.

FIG. **14** depicts a schematic of electrical connections according to example embodiments of the present disclosure.

FIG. **15** depicts a schematic of electrical connections and a plurality of clamping electrodes according to example embodiments of the present disclosure.

FIG. **16** depicts a schematic of electrical connections and a plurality of clamping electrodes according to example embodiments of the present disclosure.

FIG. **17** depicts a schematic of electrical connections and a plurality of clamping electrodes according to example embodiments of the present disclosure.

FIG. **18** depicts a schematic of electrical connections and a plurality of clamping electrodes according to example embodiments of the present disclosure.

FIG. **19** depicts a schematic of electrical connections and a plurality of clamping electrodes according to example embodiments of the present disclosure.

FIG. **20** depicts a schematic of electrical connections and a plurality of clamping electrodes according to example embodiments of the present disclosure.

FIG. **21** depicts a schematic of electrical connections and a plurality of clamping electrodes according to example embodiments of the present disclosure.

FIG. **22** depicts an example workpiece support according to example embodiments of the present disclosure.

DETAILED DESCRIPTION

Reference now will be made in detail to embodiments, one or more examples of which are illustrated in the drawings. Each example is provided by way of explanation of the embodiments, not limitation of the present disclosure. In fact, it will be apparent to those skilled in the art that various modifications and variations can be made to the embodiments without departing from the scope or spirit of the present disclosure. For instance, features illustrated or described as part of one embodiment can be used with another embodiment to yield a still further embodiment. Thus, it is intended that aspects of the present disclosure cover such modifications and variations.

Aspects of the present disclosure are discussed with reference to a "workpiece" "wafer" or semiconductor wafer for purposes of illustration and discussion. Those of ordinary skill in the art, using the disclosures provided herein, will understand that the example aspects of the present disclosure can be used in association with any semiconductor workpiece or other suitable workpiece. In addition, the use of the term "about" in conjunction with a numerical value is intended to refer to within ten percent (10%) of the stated numerical value. A "pedestal" refers to any structure that can be used to support a workpiece. A "remote plasma" refers to a plasma generated remotely from a workpiece, such as in a plasma chamber separated from a workpiece by a separation grid. A "direct plasma" refers to a plasma that is directly exposed to a workpiece, such as a plasma generated in a processing chamber having a pedestal operable to support the workpiece.

As used herein, use of the term "about" in conjunction with a stated numerical value can include a range of values within 10% of the stated numerical value.

Some plasma processing apparatuses include a workpiece support that can include an electrostatic chuck. Generally, an electrostatic chuck includes one or more electrodes embedded in a ceramic puck. When the electrode is charged with electricity, differences in the electrostatic charges in the electrode and the workpiece will hold the workpiece on the workpiece support. Existing electrostatic chucks include monopolar (e.g., a single electrode) or dipolar (e.g., to electrodes) designs. However, the present inventors have discovered that electrostatic forces generated by the electrodes can create process non-uniformities on the workpiece. For example, existing bipolar electrostatic chucks can cause side-to-side etch rate non-uniformity patterns due to the layout of the electrodes, which have a clear side-to-side pattern in electric field distribution due to the connections of the electrodes to their respective power source or sources.

Accordingly, example aspects of the present disclosure provide for a unique radial layout for the chucking (e.g., clamping) electrodes. The chucking electrodes can be thermally isolated and electrically connected in a manner resulting in a total of four isolated zones in the chucking electrodes. In general, example aspects of the present disclosure are directed to an electrostatic chuck that includes a clamping layer having one or more clamping electrodes. The clamping electrodes include a first clamping electrode defining a first clamping zone and a second clamping zone. The clamping electrodes include a second clamping electrode defining a third clamping zone and a fourth clamping zone. The first clamping zone and the second clamping zone are separated by a first gap. The first clamping zone and second clamping zone are electrically connected by at least one electrical connection extending across the first gap. The third clamping zone and the fourth clamping zone are separated by a second gap. The third clamping zone and fourth clamping zone are electrically connected by at least one electrical connection extending across the second gap.

The first and second clamping electrodes are disposed in a radial manner such that the first clamping zone is radially most inward, the second clamping zone is radially inward from the third clamping zone and radially outward from the first clamping zone, and the third clamping zone is radially inward from the fourth clamping zone and radially outward from the second clamping zone. The clamping zones can correspond to the placement of one or more heating zones defined in a heating layer with heating electrodes.

Further, the electrostatic chuck can include a thermal control system. The thermal control system can include a layer disposed in the chuck in order to distribute a thermal exchange fluid or gas (e.g., helium). The thermal control system can include one or more flow channels that are interconnected to one or more release apertures disposed in certain release zones. For example, in embodiments, the release zones of apertures can be disposed in a radial pattern corresponding to the clamping zones and/or heating zones. For example, the first zone of release apertures can be located radially most inward and the second zone of release apertures can be located radially outward from the first zone of release apertures. The third zone of release apertures can be located radially outward from the second zone of release apertures and radially inward from the fourth zone of release apertures.

In certain implementations, the electrostatic chuck can also include a sealing band. The sealing band generally sits atop at least a portion of the workpiece support surface of the electrostatic chuck, more specifically the sealing band surround an outer perimeter of the electrostatic chuck. The sealing band is configured to have a width W1 that is greater than about 3 millimeters (mm) up tot about 10 mm. Sizing the sealing band according to example aspects of the present disclosure, provides a more robust sealing band that is better able to withstand processing and cleaning conditions without being damaged such that leakage of heat exchange gas likely to occur.

The electrostatic chuck according to example embodiments of the present disclosure can provide numerous benefits and technical effects. For instance, at least two clamping electrodes can be radially arranged and connected resulting in at least four thermally isolated zones. Each thermally isolated zone can be controlled in order to improve process uniformity. Additionally, electrostatic chuck bias compensation (e.g., chucking voltage offset) can be used to actively control the etch rate uniformity and/or chemical deposition on workpieces during processing. Furthermore, disposing certain heating zones and/or zones of release apertures as provided can further enhance temperature control in the radial and azimuthal directions across the workpiece. Further, sizing the sealing band as provided herein, ensures that the sealing band is more durable and is less susceptible to erosion from plasma exposure and, therefore, less likely to leak heat exchange gas around the perimeter of the workpiece.

In addition, some plasma processing apparatuses include a workpiece support that can include an electrostatic chuck. Generally, an electrostatic chuck includes one or more electrodes embedded in a ceramic puck. When the electrode is charged with electricity, differences in the electrostatic charges in the electrode and the workpiece will hold the workpiece on the workpiece support. Existing electrostatic chucks include monopolar (e.g., a single electrode) or dipolar (e.g., two electrodes) designs. However, the present inventors have discovered that electrostatic forces generated by the electrodes can create process non-uniformities on the workpiece. For example, existing bipolar electrostatic chucks can cause side-to-side etch rate non-uniformity patterns due to the layout of the electrodes, which have a clear side-to-side pattern in electric field distribution due to the connections of the electrodes to their respective power source or sources. Many prior solutions for improving workpiece uniformity in certain plasma processing systems having electrostatic chucks focused on RF electrodes or antennas in order to generate a more uniform plasma density and/or more uniform ion energy. Other solutions focused on improved electrostatic chuck heating designs in order to provide more uniform temperature control across the wafer.

Accordingly, example aspects of the present disclosure provide for a unique electrostatic chuck assembly that includes a pixelated array of a plurality of micro-electrodes each coupled to at least one RF bias source and a clamping power source. The clamping power source is configured to provide clamping power to each of the plurality of micro-electrodes so that each of the plurality of micro-electrodes is configured to act as a clamping electrode for the workpiece. Further, a controller is provided that is configured to control the RF bias source to independently adjust one or more RF parameters of RF bias power to one of the plurality of micro-electrodes relative to at least one other of the plurality of micro-electrodes. Accordingly, each of the electrodes can be operated independently from each other in a variety of manners in order to adjust workpiece uniformity. Indeed, going from monopolar or bipolar electrode configurates to a pixelated array of a plurality of micro-electrodes as provided herein can result in an effective electrostatic chuck having clamping electrodes capable of providing necessary chucking (e.g., clamping) ability and multipurpose uniformity tuning capabilities.

The electrostatic chuck according to example embodiments of the present disclosure can provide numerous benefits and technical effects. For instance, each of the plurality of micro-electrodes in the pixelated array can be independently controlled allowing for more precise control of selected individual surface areas of the electrostatic chuck, which can aid in workpiece uniformity. For example, use of a plurality of micro-electrodes can allow an operator to modify selected sections of the electrostatic chuck, as needed, in order to adjust RF parameters, clamping functionality, and/or workpiece uniformity.

Referring to FIGS. **1**-**2**, for instance, one embodiment of a workpiece processing system **100** made in accordance with the present disclosure is shown. In the embodiment illustrated in FIG. **1**, the system includes a process chamber **9**. The process chamber **9** includes a workpiece processing station **13**. The processing station **13** includes a workpiece support **12** made in accordance with the present disclosure. The process chamber shown in FIG. **1** includes one processing station **13** for processing one workpiece, such as a semiconductor wafer. It should be understood, however, that the process chamber **9** may include more than one processing station in other embodiments. As shown, the processing station **13** includes a processing region **14**. The processing region **14** is in communication with an isolation valve **17**. Isolation valve **17** opens and closes so as to allow the workpiece to be exchanged. The isolation valve **17** seals to the process chamber wall **10**.

In the embodiment illustrated, the workpiece support **12**, or at least a portion of the workpiece support, includes an electrostatic chuck **24**. Electrostatic chucks **24** are configured to produce an electrostatic force that holds a workpiece **16** onto the top surface of the workpiece support **12**. More particularly, the electrostatic chucks function by applying one, monopolar, or two, bipolar, high DC voltages between an electrostatic chuck and the workpiece. For instance, two, bipolar DC voltages cause both positive and negative charges on one side of the first dielectric layer **28**. These charges, generate attractive Coulomb forces between the top surface of the workpiece support **12** and a workpiece **16**. As will be described in greater detail below, the workpiece support **12** includes a clamping layer having one or more clamping electrodes that enables the electrostatic chuck function. It should be understood, however, that the teachings and principles of the present disclosure are also applicable to other workpiece supports that do not necessarily comprise electrostatic chucks.

The processing station **13** is configured to receive a workpiece **16** on the workpiece support **12**. Once the workpiece **16**, such as a semiconductor wafer, is loaded into the process chamber, the workpiece **16** is subjected to an energy source in order for the workpiece **16** to undergo a desirable physical and/or chemical change. Energy sources that may be used to process workpieces can include, for instance, an ion source, a reactive chemical source, a thermal source, a plasma source, or mixtures thereof. Thermal sources that may be used to subject the workpieces to energy include light energy sources, such as, plasma arc lamps, tungsten halogen lamps, microwave, inductive, resistive heaters, or mixtures thereof.

In certain embodiments, process chamber **10** includes a plasma source for subjecting a workpiece to a plasma. The plasma is supplied by means of one or more induction coils **39** that are in communication with a RF impedance matching device (not shown) and in communication with a RF power supply (not shown). While only one induction coil **39** is shown, the disclosure is not so limited. Indeed any number of induction coils could be provided in order to generate a plasma in the process chamber **9**.

The workpiece processing system **100** of FIG. **1** is provided for purposes of illustration and discussion. Those of ordinary skill in the art, using the disclosures provided herein, will understand that the electrostatic chuck(s) according to example aspects of the present disclosure can be used in any suitable processing system (e.g., any suitable plasma processing system).

Referring now to FIG. **2**, as shown, the workpiece support **12** includes a workpiece-receiving surface **18** that is defined by a dielectric portion **20**. The dielectric portion **20** is positioned on top of a base that, in this embodiment, includes a first base portion **22** positioned over a second base portion **15**. In embodiments, the combination of dielectric portion **20**, first base portion **22**, and second base portion **15** can be referred to as the electrostatic chuck **24**. The electrostatic chuck **24**, and representative layers, is made from any suitable metallic or ceramic material. For instance, in one embodiment, the base portions **22** and **15** can be made from aluminum. The electrostatic chuck **24** can also include alumina, aluminum nitride, yttria, zirconia, and/or any other chemically resistant ceramic or plastic material. The electrostatic chuck **24** is attached to a workpiece support pedestal **57**. The purpose of the pedestal **57** is to provide rigid mechanical support for the electrostatic chuck **24** and to provide both thermal and electrical isolation from the process chamber **9**.

As described above, the dielectric portion **20** is positioned on top of the first base portion **22** and defines the workpiece-receiving surface **18**. The dielectric portion **20** can be made from any suitable dielectric material, such as a ceramic material. The dielectric portion can comprise multiple layers of a dielectric material or can comprise a single layer. In the embodiment the dielectric portion **20** includes a first dielectric layer **28** positioned on top of a second and thicker second dielectric layer **30**. The first dielectric layer **28**, for instance, can have a thickness of about 0.4 to about 1 mm, while the second dielectric layer **30** can have a thickness of from about 2 mm to about 5 mm.

As shown in FIG. **2**, the workpiece support **12** can further be in communication with an RF conduit **36** that is in communication with an RF impedance matching device (not shown) in communication with an RF power supply **38** for supplying an RF bias power to the workpiece.

In an alternative embodiment, the RF source power can be coupled to the workpiece support **12** through an RF impedance matching device (not shown) that is in communication with a RF conduit **36**. In this embodiment, there is no additional RF power supplied to the processing station **13**. In an alternative embodiment, no RF source power is coupled to the workpiece support **12**. During workpiece processing, the RF power source can be energized to produce ions and electrons in the plasma for desired chemical reactions with a top surface of the workpiece **16**. In other embodiments, the RF power source provides independent control of the energy that ions have when they strike the top surface of the workpiece. The RF power supply and the DC power supply can both be grounded using any suitable technique. In one embodiment, for instance, both RF and DC power supplies may be grounded to an electrode in communication with the processing chamber. In the embodiments illustrated, the process chamber employs inductive-coupled RF power to generate and maintain a plasma necessary for workpiece processing. The RF bias power is capacitively coupled to the plasma through the workpiece support **12**.

In order to load and unload workpieces on the workpiece-receiving surface **18**, the workpiece support **12** can include any suitable mounting device. For instance, in one embodiment, the workpiece support **12** may include a plurality of lift pins (not shown) that can be used to properly position a workpiece **16** on the workpiece-receiving surface **18** and to elevate and lower the workpiece **16** on the workpiece-receiving surface. In this regard, the workpiece support **12** can include a plurality of pin channels for a lift pin assembly. In one embodiment, for instance, the workpiece support **12** may include three pin channels for accommodating three pins.

In embodiments, the workpiece processing system **100** can include a controller **175**. The controller **175** controls various components in processing chamber **9** to direct processing of workpiece **16**. For example, controller **175** can be used to control power sources (e.g., DC power source, AC power source, and/or RF power source) connected to the electrodes in the clamping layer **40** and/or heating layer **50**. Additionally and/or alternatively, controller **175** can be used to control the thermal management system **70** in order to control or maintain a desired workpiece temperatures. The controller **175** can also implement one or more process parameters, such as controlling the gas flow controllers and/or altering conditions of the processing chamber **9** during processing of the workpiece **16**. The controller **175** can include, for instance, one or more processors and/or one or more memory devices. The one or more memory devices can store computer-readable instructions that, when executed by the one or more processors, cause the one or more processors to perform operations, such as any of the control operations described herein.

Referring now to FIG. **3**, the electrostatic chuck **24** portion of the workpiece support **12** is shown. As shown, a workpiece **16** is placed on the workpiece-receiving surface **18**. A sealing band **80** is disposed around a perimeter of the electrostatic chuck **24** and is disposed on at least a portion of the workpiece-receiving surface **18**. The sealing band **80** will be further discussed herein. A clamping layer **40** is disposed between the first dielectric layer **28** and the second dielectric layer **30**. The clamping layer **40** can include one or more clamping zones **42**, **44**, **46**, **48**, which will be discussed further herein. A heating layer **50** is disposed underneath of the clamping layer **40** in the z-direction. The heating layer **52** can be disposed within the second dielectric layer **30** or between the second dielectric layer **30** and the first base portion **22**. The heating layer includes one or more heating zones **52**, **54**, **56**, **58**, which will be discussed further herein. A thermal control system **70** is disposed in the electrostatic chuck **24**. The thermal control system **70** can be disposed within the second dielectric layer **30** or the first base portion **22**. The Similar to the clamping layer **40** and the heating layer **50**, the thermal control system **70** includes one or more zones **72**, **74**, **76**, **78** of release apertures **73** for releasing a heat exchange fluid or gas in order to control the temperature of the workpiece **16**. The thermal control system **70** will be discussed further herein.

As shown in FIGS. **3** and **4**, in one embodiment in order to form the electrostatic chuck **24**, a clamping layer **40**, including one or more clamping electrodes, can be positioned within the electrostatic chuck **24**. For example, in embodiments, the clamping layer **40** can be positioned between the first dielectric layer **28** and the second dielectric layer **30**. The one or more clamping electrodes present in the clamping layer **40** can be placed in communication with a DC power supply **34** as shown in FIG. **2**. Two different DC voltages can be supplied by a single DC power supply or by two independent power supplies. The DC power supply **34** supplies the voltages necessary to create an electric field for producing electrostatic attraction between the workpiece-receiving surface **18** and a workpiece **16** held on the surface. The amount of voltage created by the DC power supply can be used to adjust the amount of electrostatic attraction. Further, when it is necessary to remove the workpiece **16** from the workpiece support **12**, the DC power supply can be turned off so that no voltage is being produced or can create a reverse polarity voltage from the starting potential. DC voltages typically vary from about 500 to 2000 volts.

As shown in FIG. **4**, the clamping layer **40** can include one or more electrodes, such as at least two electrodes **41**,**43**, disposed in radial arrangement. The first clamping electrode **41** can be coupled to a negative charge source, while the second clamping electrode **43** can be coupled to a positive charge source. In other embodiments, however, it is contemplated that either the first or second clamping electrode **41**,**43** could be coupled to either a positive or a negative charge source. For example, in embodiments, the first clamping electrode **41** is coupled to a negative DC voltage and the second clamping electrode **43** is coupled to a positive DC voltage. Furthermore, the first clamping electrode **41** and the second clamping electrode **43** can be coupled to a DC power source, AC power source, and/or a RF power source. In embodiments, both the first clamping electrode **41** and the second clamping electrode **43** can be coupled to the same RF power source.

Furthermore, as shown in FIG. **4**, the clamping layer **40** includes a first clamping electrode **41** and a second clamping electrode **43** disposed in radial arrangement. That is, the first clamping electrode **41** is disposed radially inward from the second clamping electrode **43**. The first clamping electrode **41** defines a first clamping zone **48** and a second clamping zone **46**. The second clamping electrode **43** defines a third clamping zone **44** and a fourth clamping zone **42**. As shown, the first clamping zone **48** is disposed radially most inward. The second clamping zone **46** is disposed radially outward from the first clamping zone **48** and radially inward from the third clamping zone **44**. The fourth clamping zone **42** is disposed radially most outward.

Each of the clamping zones **42**, **44**, **46**, and **48** can be thermally isolated from one another. For example, the first clamping zone **48** and the second clamping zone **46** can be separated by a gap **45***a*. The third clamping zone **44** and the fourth clamping zone **42** can also be separated by a gap **45***b*.

Furthermore, gap **45***a* reduces thermal conduction between the first clamping zone **48** and the second clamping zone **46** and the second gap **45***b* reduces thermal conduction between the third clamping zone **44** and the fourth clamping zone **42**. The gaps **45***a*,**45***b* can include an air gap or can comprise any suitable material. For example, in certain embodiments, the gaps **45***a*,**45***b* comprise a dielectric material (e.g., ceramic material).

One or more electrical connections **47** can be used to couple first clamping zone **48** with the second clamping zone **46**. For example, a plurality of electrical connections **47** can be used, such as at least five electrical connections **47**. Similarly, one or more electrical connections **49** can be used to couple the third clamping zone **44** to the fourth clamping zone **42**. The number of electrical connections **49** can include more than 1, such as more than 5, such as more than 10. In certain embodiments, the number of electrical connections **47** connecting the first and second clamping zones **48**,**46** can be less than the number of electrical connections **49** connecting the third and fourth clamping zones **44**, **42**.

While each of the two clamping electrodes **41** and **43** are thermally isolated into two zones each, they are connected via the electrical connection **47** or **49** in order to keep them at approximately the same electrical potential. For example, in embodiments, the first clamping zone **48** and second clamping zone **46** carry the same chucking voltage for the positive pole, while the third clamping zone **44** and fourth clamping zone **42** carry the same chucking voltage for the negative pole. Generally, the offset between the positive chucking voltage and the negative chucking voltage can either target balancing the clamping forces in order to compensate for a self-DC bias on the workpiece or can be purposely operated in an unbalanced mode for uniformity tuning purposes. For example, a workpiece can be processed and the uniformity of the workpiece can be assessed. Upon assessment if uniformity is at issue, the electrostatic chuck bias can be adjusted in order to adjust workpiece uniformity for workpieces processed in the future. For example, the clamping voltage of either the first clamping electrode **41** or the second clamping electrode **43** can be adjusted in order to adjust workpiece uniformity.

Furthermore, as noted, the clamping electrodes **41** and **43** can be connected to any suitable power source or voltage source (e.g., a DC power source or an RF power source). In certain embodiments, the clamping electrodes **41**,**43** are coupled to a voltage source (e.g., a high DC voltage source) the voltage source is configured to provide a DC offset ad adjustment to balance one or more clamping forces or to adjust workpiece processing uniformity. In certain configurations, the clamping electrodes are coupled to a bipolar high voltage supply (e.g., a bipolar high DC voltage supply). In certain configurations, each of the clamping zones **42**, **44**, **46**, and/or **48** can be operated independently from each other in order to adjust workpiece uniformity. For instance, in embodiments, a different amount of power output and/or a different power source itself can be applied to any of the clamping zones **42**, **44**, **46**, and **48** in order to adjust workpiece uniformity. For example, a different amount of DC voltage, RF power output, and/or a different power source can be applied to any of the clamping zones **42**, **44**, **46**, **48** in order to adjust workpiece uniformity. For example, in certain embodiments, application of different amounts of DC voltage and/or RF power applied across the clamping zones **42**, **44**, **46**, **48** can modify the clamping electrodes **41**,**43** so as to provide a tri-polar or quadra-polar electrostatic chuck. Furthermore, the clamping electrodes can be connected to a DC power source or an RF power source with one or more capacitors disposed along the RF path in order to prevent DC voltage from interfering with or accessing the RF delivery. Additionally or alternatively, an inductor and/or resistor in series can be disposed in the DC path to prevent RF voltage from accessing the DC voltage supply.

Additionally, one or more traces can be utilized in order to arrange the clamping zones **42**, **44**, **46**, **48** in any type of electrical configuration. For example, the first clamping zone **48** and the third clamping zone **44**, could be electrically coupled to one or more traces embedded in a layer of the electrostatic chuck **24** to form the first clamping electrode **41** and the second clamping zone **46** and the fourth clamping zone **42** could be electrically coupled to one or more traces embedded in a layer of the electrostatic chuck **24** to form the second clamping electrode **43**. Moreover, in embodiments, the first clamping zone **48** and the fourth clamping zone **42** could be electrically coupled to one or more traces embedded in a layer of the electrostatic chuck **24** to form the first clamping electrode **41** and the second clamping zone **46** and third clamping zone **44** could be electrically coupled to one or more traces embedded in a layer of the electrostatic chuck **24** to form the second clamping electrode **43**. In such embodiments, the traces used to connect different clamping zones **42**, **44**, **46**, **48** can be located generally in a layer of the electrostatic chuck that is underneath of the clamping layer **40**. Once the selected clamping zones are coupled via a trace, the trace can then be connected to any suitable power source as described herein.

In one or more embodiments, a heating layer **50** can be disposed in the workpiece support **12**. For example, FIG. **5** illustrates different zones of the heating layer **50**. For example, the heating layer **50** can include one or more electrodes **51**, such as a plurality of electrodes **51***a*, **51***b*, **51***c*, **51***d* arranged in a radial pattern. For example, in certain embodiments, the heating layer **50** includes at least four electrodes **51***a*, **51***b*, **51***c*, **51***d*. Each of the electrodes **51***a*, **51***b*, **51***c*, **51***d* can be connected to a suitable AC or DC power source. In certain embodiments, the plurality of heating electrodes **51***a*, **51***b*, **51***c*, **51***d* are disposed in a radial manner to form a first heating zone **58**, a second heating zone **56**, a third heating zone **54**, and a fourth heating zone **52** as shown in FIG. **5**. The heating zones **52**, **54**, **56**, and **58** can be disposed in any manner on or within the heating layer **50** in the electrostatic chuck **24**.

In certain embodiments, the heating zones **52**, **54**, **56**, and **58** correspond to the clamping zones **42**, **44**, **46**, and **48** present in the clamping layer **40**. For example, as shown in FIG. **3**, the first heating zone **52** is disposed under the first clamping zone **42** in the z-direction. The second heating zone **56** is disposed under the second clamping zone **46** in the z-direction. The third heating zone **54** is disposed under the third clamping zone **44** in the z-direction. The fourth heating zone **52** is disposed under the fourth clamping zone **42** in the z-direction. Additionally, the widths of the heating zones **52**, **54**, **56**, **58** are substantially the same as the widths of the clamping zones **42**, **44**, **46**, **48**. For example, the width of the first heating zone **58** is substantially the same as the width of the first clamping zone **48**. The width of the second heating zone **56** is substantially the same as the width of the second clamping zone **46**. The width of the third heating zone **54** is substantially the same as the width of the third clamping zone **44**. The width of the fourth heating zone **52** is substantially the same as the width of the fourth clamping zone **42**. Disposition of the heating zones **52**, **54**, **56**, **58** in relation to the clamping zones **42**, **44**, **46**, **48** can help with thermal isolation from zone to zone radially. Furthermore, each heating zone **52**, **54**, **56**, **58** overlaps with its corresponding clamping zone **42**, **44**, **46**, **48** to help with thermal transition from zone to zone radially.

Each of the heating zones **52**, **54**, **56**, **58** can be independently controlled in order to adjust heating across different radial regions of the workpiece during processing. For example, each heating zone **52**, **54**, **56**, **58** can be formed from at least one electrode, each individual electrode (e.g., **51**a, **51**b, **51**c, **51**d) used to form the separate heating zones **52**, **54**, **56**, **58** can be independently connected to a power source. Accordingly, different amounts and/or types of power can be supplied to each electrode in order to adjust the temperature for each of the heating zones **52**, **54**, **56**, **58**.

In order to connect each of the electrodes (e.g., clamping electrodes and/or heating electrodes) present in the electrostatic chuck to the appropriate or desired power source, one or more traces and/or vias can be used to connect the electrodes to the power sources. Referring to FIGS. **6**-**8**, for example, in certain embodiments a trace **60** is used to connect the second clamping electrode **43** to a suitable power source. For instance, the trace **60** can run from the second electrode **43** towards the center of the clamping layer **40**. In certain embodiments, the trace **60** is run in a layer located underneath of the clamping electrodes **41**, **43** towards a centrally-located delivery socket location(s) in order to couple the second clamping electrode **43** to a suitable power source. Furthermore, in embodiments, one or more vias **61** can be used to connect the trace **60** to the second electrode **43** and to the delivery socket location. Vias **61** can be used in order to run the trace **60** in a layer underneath of the clamping layer **40**, that is the trace **60** is not located in the same plane orthogonal to the z-direction as the clamping layer **40**. Similarly, one or more traces **60** can be run from each of the heating electrodes (e.g., **51**a, **51**b, **51**c, **51**d) towards centrally-located delivery socket locations in order to couple the heating electrodes to a suitable power source. Similar to the clamping electrode arrangement, one or more vias can be used in order to run the traces **60** underneath of the heating layer **50**, that is the trace **60** (or traces) used to connect the heating electrodes to the power source(s) is not located in the same plane orthogonal to the z-direction as the heating layer **50**.

In certain embodiments, the workpiece support **12** can further include a thermal control system **70**. The thermal control system **70** can include one or more channels **71** for circulating a thermal exchange fluid or a thermal exchange gas (e.g., helium). The thermal control system **70** can be included as a layer disposed within the electrostatic chuck. For example, in certain embodiments the thermal control system **70** layer can be located underneath of the workpiece **16** when the workpiece is disposed on the workpiece support **12**. For example, in certain embodiments the thermal control system **70** can be disposed between the workpiece **16** and the clamping layer **40**. In certain other embodiments, however, it is contemplated that the thermal control system **70** could be located between the clamping layer **40** and the heating layer **50** or underneath of the heating layer **50**. The thermal control system **70** can be disposed within the electrostatic chuck in any manner suitable for processing of workpieces **16** in the processing chamber. Referring back to FIG. **3**, the thermal control system **70** is disposed underneath of both the clamping layer **40** and the heating layer **50** in the z-direction.

As shown in FIG. **9**, the thermal control system **70** includes one or more channels **71** and also includes one or more release apertures **73**. The one or more channels **71** are interconnected via a pattern to each of the release apertures **73**. The release apertures **73** are organized according to zones **72**, **74**, **76**, **78** of release apertures **73**. A single thermal exchange fluid or thermal exchange gas inlet **75** is shown. For example, in embodiments, the thermal control system **70** includes a first zone **78** of release apertures **73**, a second zone **76** of release apertures **73**, a third zone **74** of release apertures **73**, and a fourth zone **72** of release apertures **73**. The first zone **78** of release apertures **73** is disposed radially most inward. The second zone **76** of release apertures **73** is disposed radially outward from the first zone **78** of release apertures **73** and radially inward from the third zone **74** of release apertures **73**. The third zone **74** of release apertures **73** is disposed radially inward from the fourth zone **72** of release apertures **73** and radially outward from the second zone **76** of release apertures **73**. While at least four zones (e.g., **72**, **74**, **76**, **78**) of release apertures **73** are shown, the disclosure is not so limited. Indeed, any number of zones of release apertures could be configured into the thermal control system **70** disclosed herein. Further, the first zone **78** of release apertures **73** includes the fewest number of release apertures **73** as compared to the other zones **72**, **74**, **76**. The second zone **76** of release apertures **73** includes more release apertures **73** than the first zone **78** of release apertures **73** but fewer release apertures **73** as compared to the third zone **74** of release apertures **73**. The third zone **74** of release apertures **73** includes more release apertures **73** than the second zone **76** of release apertures **73** but fewer release apertures **73** as compared to the fourth zone **72** of release apertures **73**. The fourth zone **72** of release apertures **73** includes the most release apertures **73** as compared to the other zones **74**, **76**, **78**.

In embodiments, each of the zones **72**, **74**, **76**, **78** of release apertures **73** generally correspond to the one or more heating zones **52**, **54**, **56**, **58** and/or clamping zones **42**, **44**, **46**, **48**, respectively. Namely, the zones **72**, **74**, **76**, **78** of release apertures **73** can be disposed underneath or on top of the corresponding zones of the clamping layer **40** and the heating layer **50**. Such disposition is illustrated in FIG. **3**. In certain embodiments, the zones **72**, **74**, **76**, **78** of release apertures can be disposed in a layer located underneath of both the clamping layer **40** and the heating layer **50**. Accordingly, one or more heat exchange conduits can be drilled through the workpiece-receiving surface **18**, the clamping layer **40**, and the heating layer **50**, so that the thermal exchange fluid or gas released from the release apertures **73** located in each of the zones **72**, **74**, **76**, **78** can come into contact with a backside of the workpiece **16** in order to adjust the temperature of the workpiece **16**. In other embodiments, however, the thermal control system **70** can be located directly underneath of the workpiece **16** when it is held on the workpiece support **12**. For instance, the zones **72**, **74**, **76**, **78** of release apertures **73** can be located within or just below the first dielectric layer **28**. In embodiments, one or more conduits can be drilled through the only the first dielectric layer **28** so that the heat exchange gas or heat exchange fluid released from the release apertures **73** located in each of the zones **72**, **74**, **76**, **78** can come into contact with a backside of the workpiece **16** in order to adjust the temperature of the workpiece **16**.

Referring now to FIG. **10**, in certain embodiments, (e.g., those including a thermal control system capable of helium distribution), the electrostatic chuck **24** can include a sealing band **80**. The sealing band **80** generally surrounds an outer perimeter of the electrostatic chuck **24** including at least a portion of the workpiece-receiving surface **18**. The sealing band **80** is configured to have a width W1 that is greater than about 3 millimeters (mm) up to about 10 mm, such as greater than 4 mm up to about 9 mm, such as greater than 5 mm up to about 8 mm, such as greater than 5 mm, up to about 7 mm. The sealing band **80** generally sits atop the electrostatic chuck **24** in order to seal any thermal exchange fluid and/or gas (e.g., helium) underneath the workpiece **16** when the workpiece **16** is chucked on to the electrostatic chuck **24**. Further, electrostatic chucks often go through in-situ dry-cleaning (ISD) and can further go through off-situ cleaning during maintenance. If the sealing band is damaged or worn after hours of use or during cleaning, such damage can cause leakage of thermal exchange gas (e.g., helium) such that the workpiece temperature is not maintained as it should be. Further, if thermal exchange gas (e.g., helium) is able to seep out and around the sealing band such that it has access to the top of the workpiece during process, this can cause further uniformity issues during workpiece processing. Accordingly, the width W1 of the sealing band **80** provided herein is such that the sealing band **80** is more robust and is better able to withstand processing and cleaning conditions without being damaged such that leakage of thermal exchange gas is not likely to occur.

FIG. **11** illustrates a top-down view of a plurality of clamping electrodes **200**. As shown in the embodiments illustrated in FIG. **11**, at least four clamping electrodes **202**, **204**, **206**, **208**, are provided. Furthermore, while FIG. **11** illustrates an embodiment including four clamping electrodes **200**, the disclosure is not so limited. Indeed, any number of clamping electrodes **200** can be included according to desired processing parameters. While the clamping electrodes can be disposed in any pattern, as shown, they are disposed in a concentrically radial pattern. In embodiments, the plurality of clamping electrodes **200** can be formed into a clamping layer **212** as part of the dielectric portion **20** of the electrostatic chuck **24**. The first clamping electrode **202** is the innermost disposed electrode with the second clamping electrode **204** disposed radially outward from the first clamping electrode **202** and radially inward from the third clamping electrode **206**. The third clamping electrode **206** is disposed radially outward from the second clamping electrode **204** and radially inward from the fourth clamping electrode **208**. The fourth clamping electrode **208** is disposed radially most outward. As noted, each of the clamping electrodes **202**, **204**, **206**, **208** are coupled to one or more power sources that can be individually configured, as will be further described hereinbelow.

FIGS. **12-13** illustrate top-down views of a pixelated array of a plurality of micro-electrodes **210**. As shown, the plurality of micro-electrodes **210** are disposed in a pattern arrangement generally about a clamping layer **212** that can be incorporated into the electrostatic chuck assembly. For example, the pixelated array of micro-electrodes **210** can be arranged in any pattern such as square or rectangular patterns. For example, the micro-electrodes **210** can be disposed in a square grid pattern having the same number of columns and rows. In other embodiments, the micro-electrodes **210** can be arranged in a rectangular pattern. The micro-electrodes **210** can also be arranged in a variety of circular patterns, including radially extending circular patterns, having rows of concentric circles of micro-electrodes **210** disposed to form the pixelated array. The micro-electrodes **210**, themselves, can include any suitable shape including circular (as shown in FIG. **12**), ovular, triangular, rectangular, square (as shown in FIG. **13**), and/or any combination thereof. The micro-electrodes **210** can also include strips or plates arranged in any configuration or pattern. In some embodiments, the micro-electrodes **210** can be randomly dispersed across the clamping layer **212** and/or be formed from a plurality of shapes distributed across the clamping layer **212**. In certain embodiments, the micro-electrodes **210** can include pixelated micro-electrodes. Each micro-electrode **210** can be microns in size. For example, the diameter of each micro-electrode **210** can be in the range of microns. Furthermore, while any number of micro-electrodes **210** can be used, in certain embodiments the electrostatic chuck **24** and/or dielectric portion **20** includes from about 2 micro-electrodes up to about 200 micro-electrodes, such as from about 20 to about 180 micro-electrodes, such as from about 40 to about 160 micro-electrodes, such as from about 60 to about 140 micro-electrodes, such as from about 80 to about 120 micro-electrodes.

As noted above, each of micro-electrodes **210** can be coupled to one or more power sources. For example, in certain embodiments each of the micro-electrodes **210** (illustrated in FIGS. **12-13**) can each be connected to different power sources. Suitable power sources can include any suitable DC power source, AC power source, and/or RF power source. In certain embodiments, the DC power source includes a DC power source capable of producing a high voltage DC current. For example, in certain embodiments each of the micro-electrodes **210** are electrically coupled to at least one RF bias source and at least one clamping power source (e.g., a DC power source). In certain embodiments, the RF bias source and the clamping power source can be the same or different. Further, the clamping power source can include any suitable DC power source, AC power source, and/or RF power source. The clamping power source is configured to provide clamping power to each of the plurality of micro-electrodes **210** so that each of the plurality of micro-electrodes is configured to act as a clamping electrode for the workpiece **16**. Additionally and/or alternatively, in embodiments, each of the plurality of micro-electrodes **210** can be coupled to an RF bias source. In certain embodiments, the RF bias source includes a plurality of RF bias sources, each one of the RF bias sources is coupled to at least one of the plurality of micro-electrodes **210**. The controller **175** can be configured to control the RF bias source(s) in order to independently adjust RF parameters of RF bias power to each of the plurality of micro-electrodes **210**. For example, in certain embodiments, the RF parameters can include one or more of RF power, RF frequency, or RF phase.

FIG. **14** depicts one embodiment in which the electrical connections **300** of seven micro-electrodes **210** are diagrammed (diagram also shown in FIG. **15**). As depicted, each of the seven micro-electrodes **210** can be connected to a power source (e.g., a high voltage DC power supply or a RF bias source) via one or more electrical connections **300**. Although not shown, each of the other micro-electrodes **210** provided in the pixelated array can also be connected to a suitable power source via one or more electrical connections. A DC power source is illustrated in FIG. **14**, but the power source could be an RF source as indicated above. The array of micro-electrodes **210** can be connected in either monopolar operation (e.g., the same polarity for all of the micro-electrodes) or in bipolar operation (e.g., with negative polarity for some selected micro-electrodes and positive polarity for the rest of the micro-electrodes). The bipolar configuration can be localized and/or global.

In some embodiments, each of a plurality of clamping electrodes **210** can be switched according to a pulse-width modulation control scheme. For instance, FIG. **16** depicts a diagram of a plurality of micro-electrodes **210** being switched together at an individually-configured frequency $f_{individual}$, where all the depicted electrodes **210** are provided with a fixed voltage (e.g., which can be the same or different). For example, each clamping electrode **210** is configured to an electrical connection **300** having an electrical switching element **302** associated therewith. Each micro-electrode **210** and connected electrical connection **300** are each coupled to individual power sources **304**. Although a DC power source is illustrated in FIG. **16**, the power sources **304** can include any suitable DC power source, AC power source, and/or RF power source.

FIG. **17** depicts a diagram of a plurality of micro-electrodes being switched together each at an individually-configured frequency $f_{individual}$, where all the depicted micro-electrodes **210** are provided with an adjustable voltage (e.g., which can be adjusted to be the same or different). As shown in FIG. **17**, all of the switching elements **302** can be turned on and off at the same frequency although the individually-configured frequency $f_{individual}$ for each micro-electrode **210** can be different from each other to further enable ion energy distribution uniformity. In yet further embodiments, in addition to the adjustable voltage sources, each switching element **302**, can be switched at an individually-configured frequency $f_{individual}$, as shown in FIG. **18**. In embodiments, the electrical switching elements **302** can include SiC MOSFETs with high breakdown voltage ratings that can be configured to be controlled with signals at their gates. Other suitable switches can be used without deviating from the scope of the present disclosure.

In some embodiments, the individually-configured switching elements **302** can be tied to a common power source **306**, as shown in FIGS. **19-20**. For example, common power source **306** can include any suitable DC power source, AC power source, and/or RF power source. For example, each of the RF bias source and/or clamping power sources for the individual micro-electrode **210** can be offset from a main voltage that is provided by a main power source (e.g., from the common power source **306**) for the respective desired source. For example, each of the micro-electrodes **210** can share one common power source with adjustments available to each individual micro-electrode **210**. For example, in certain embodiments each of the plurality of micro-electrodes **210** can be coupled to one main DC power source with individual clamping voltages supplied to each of the individual micro-electrodes **210** by multiple off-set DC supplies in series with the main DC power source. The off-set DC supplies can have a lower max voltage range than that of the main DC power source. In embodiments, the clamping power source (e.g., a DC power source) is configured to provide a plurality of different DC voltages to each of the micro-electrodes **210**. In other embodiments, each of the plurality of micro-electrodes **210** can be coupled to one main RF power source (e.g., RF bias source) with individual RF bias voltages suppled to each of the individual micro-electrodes **210** by multiple off-set RF supplies in series with the main RF power source.

In certain embodiments, the common power source **306** includes a DC power source that can be switched at a very high duty cycle with a main frequency f_{main} that is 10 to 1000 times higher than the individually-configured frequency $f_{individual}$. For yet further control, in addition to independently adjusting the individually-configured frequency $f_{individual}$ for each switching element **302**, the main power source **306** can be switched and/or operated at a main frequency f_{main}, as shown in FIG. **20**. In such embodiments, the main frequency f_{main} is higher than each of the individually-configured frequencies $f_{individual}$ for each of the plurality of micro-electrodes **210**. For instance, in embodiments, the plurality of micro-electrodes **200** are powered by a DC power source configured to be switched on and off at a main frequency f_{main} that is higher than an individually-configured frequency $f_{individual}$ for each of the plurality of micro-electrodes **200**. For example, in certain embodiments, the controller **175** can be used to operate switching elements **302** using a pulse width modulation to adjust a voltage applied to at least one micro-electrode **210** coupled to the respective switching element **302**. For example, in certain embodiments the common power source **306** can include a clamping power source (e.g., a DC power source) that is configured to provide a plurality of different DC voltages to each of the plurality of micro-electrodes **210**. The controller **175** can be configured to control each of the switching elements **302** using pulse width modulation to adjust a voltage applied to each of the micro-electrodes **210** coupled to their respective switching elements **302**.

Furthermore, the micro-electrodes **210** described with respect to FIG. **20**, can also be configured to perform RF biasing with respect to the workpiece with RF frequency. For instance, in certain embodiments, the common power source **306** can include an RF bias source configured to apply RF bias to at least one of the micro-electrodes **210** by controlling the switching element **302** using pulse width modulation at a frequency in a range of about 1 kHz to 2 MHz. In embodiments, the RF bias source can include the clamping power source, where the clamping power source includes a DC power source coupled to at least one of the micro-electrodes **210** via a switching element **302**. The controller **175** can be configured to apply RF bias to the at least one of the micro-electrodes **210** by controlling the switching element **302** using pulse width modulation. The controller **175** can be configured to apply RF bias to at least one of the micro-electrodes **210** by controlling the switching element **302** using pulse width modulation at a frequency in a range of about 1 kHz to about 2 MHz. Accordingly, in such embodiments, a DC power source can be configured to provide RF bias to each of the individual micro-electrodes **210** as desired. Furthermore, in embodiments where the common power source **306** includes a single DC power source coupled to each of the micro-electrodes **210** via the switching network (as shown in FIGS. **19-20**), the controller **175** can be further configured to selectively control one or more switching elements **302** in the switching network to selectively apply clamping power and/or RF bias to one or more of the plurality of micro-electrodes **210**.

Further, certain areas or portions of the micro-electrodes **210** can be superimposed with RF power at a main frequency f_{main} on top of the bias RF power delivered at a bias frequency f_{bias} from the RF power source to a baseplate and/or separate RF electrode embedded in the electrostatic chuck **24**. The bias frequency f_{bias} can be higher as compared to the main frequency f_{main}. For example, bias frequency f_{bias} can be in the range of from about 400 kHz to about 13.56 MHz. Further, the main frequency f_{main} should be low enough in the kHz range so that the DC power source being switched at the main frequency f_{main} can be delivered to the micro-electrodes **210** with impedance match.

Yet further control can be obtained as shown in FIG. **21**, which combines the control schemes of the diagrams shown in FIGS. **18** and **20**. Additionally, in certain embodiments additional reactive components can be included in series with the micro-electrodes to form series resonance. Furthermore, in certain embodiments, snubber circuitry could be added to such embodiments to suppress oscillations.

In certain of the disclosed embodiments, the main frequency f_{main} can be in the range of from about 1 kHz to about 2 MHz and the individually-configured frequencies

$f_{individual}$ for each of the electrodes can be in the range of from about 1 Hz to about 1 kHz.

FIG. **22** depicts one embodiment in which the micro-electrodes **210** are individually powered, with the micro-electrodes **210** being fed from power sources superimposed onto the bias RF input from the main pedestal RF bias source (e.g., the micro-electrodes are DC isolated from the pedestal by the dielectric portion ceramic puck). In various embodiments, any of the wiring schemes shown in FIGS. **14-21** can be incorporated into the assembly of FIG. **22** and referenced to the bias voltage applied to the pedestal. In this manner, each of the control schemes shown in FIGS. **14-21** can control voltage(s) superimposed on the bias voltage, which can be modulated at a bias frequency f_{bias}, as discussed above.

Still referring to embodiments depicted in FIG. **22**, in certain embodiments, each of the micro-electrodes **210** include pixelated micro-clamping electrodes that have small capacitance and can be embedded into the ceramic puck **26** or can be disposed on top of the ceramic puck **26**. For example, the plurality of clamping electrodes **200** can be disposed on the top surface of the dielectric portion **20** and can extend from the top surface of the dielectric surface **20**. In such embodiments, an optional dielectric layer **27** (e.g., a thin ceramic layer) can be disposed between the plurality of micro-electrodes **210** and the workpiece. DC current or voltage can be supplied to each of the micro-electrodes **210** via a suitable DC power source. In certain embodiments, the DC current applied to each of the micro-electrodes **210** is very small, such as in the scale of micro-amperes or even lower depending on the materials of the dielectric layer **20** and/or other leakages associated along the delivery path (e.g., the electrical connections **300**) from the DC power source **34** to the micro-electrodes **210**. When the DC source **34** (e.g., a high voltage DC supply) is switched on and off at a relatively low frequency and/or proper duty cycle in the sub-kHz range (as shown in FIG. **14**), the voltage on the micro-electrodes **210** responds uniformly to a square, switching waveform with very short transient in order to maintain clamping functionality of the micro-electrodes **210**. Further, in such embodiments, the electrical connections **300** should be as short as possible in order to minimize strays in the DC delivery path along the electrical connections **300** while still having sufficient RF impedances to block the main RF power from both bias and plasma sources with small inductors and large capacitors to form parallel resonances of the main RF frequencies of bias and source. In such embodiments, the micro-electrodes **210** may be located on a top surface of the dielectric portion **20**. The micro-electrodes **210** can be embedded in the dielectric portion or are physically located above the dielectric portion **20** with the DC power source isolated by the dielectric portion **20** from the baseplate of the electrostatic chuck **24** that carries the bias RF power. Accordingly, each of the micro-electrodes **210** can be configured to act as finely-tuned bias RF electrodes having their power superimposed on top of the main bias RF power, as shown in FIG. **14**. The voltage levels supplied to the micro-electrodes **210** can be varied in order to enable localized uniformity tuning capability.

As noted, in some embodiments, the electrical connections **300** within the assembly can be kept short to reduce any stray capacitances (and/or other losses) in the DC delivery path while having sufficient RF impedances to block the main RF power from the bias and/or plasma sources with inductors and/or capacitors to form parallel resonances for the main RF frequencies of the bias and/or plasma source.

One example embodiment of the present disclosure is directed to an electrostatic chuck. The electrostatic chuck can include a workpiece support surface configured to support a workpiece during processing. The electrostatic chuck can include one or more clamping electrodes defining a clamping layer. The electrostatic chuck can include one or more heating electrodes defining a heating layer. The electrostatic chuck can include a thermal control system. The electrostatic chuck can include a sealing band surrounding an outer perimeter of the electrostatic chuck including at least a portion of the workpiece support surface, the sealing band having a width greater than about 3 millimeters (mm) up to about 10 mm.

In some embodiments, the clamping electrodes are connected to a DC power source, AC power source, and/or an RF power source.

In some embodiments, the one or more clamping electrodes comprise a first clamping electrode and a second clamping electrode.

In some embodiments, the first clamping electrode is coupled to a negative DC voltage, and the second clamping electrode is coupled to a positive DC voltage.

In some embodiments, the thermal control system comprises one or more flow channels for circulating a thermal exchange fluid or a thermal exchange gas.

In some embodiments, the thermal exchange gas comprises helium gas.

In some embodiments, the flow channels are interconnected to a first zone of release apertures, a second zone of release apertures, a third zone of release apertures, and a fourth zone of release apertures.

In some embodiments, the first zone of release apertures is located innermost radially, wherein the second zone of release apertures is located radially outward from the first zone of release apertures, wherein the third zone of release apertures is located radially outward from the second zone of release apertures and radially inward from the fourth zone of release apertures.

In some embodiments, the second zone of release apertures includes more apertures than the first zone of release apertures, wherein the third zone of release apertures includes more apertures than the second zone of release apertures, wherein the fourth zone of release apertures includes more release apertures than the third zone of release apertures.

In some embodiments, the sealing band is configured to seal the workpiece support surface, such that thermal exchange gas is not capable of leaking around an edge of the workpiece.

In some embodiments, the electrostatic chuck defines a first outer boundary and the clamping layer defines a second outer boundary, wherein a first distance D1 between the first outer boundary and the second outer boundary is greater than a second distance D2 defined between one or more turns of the first electrode and/or second electrode in the clamping layer, wherein D1 is greater than about 2 millimeters (mm).

Another example embodiment of the present disclosure is directed to a workpiece processing apparatus. The apparatus includes a processing chamber. The apparatus includes a workpiece support disposed in the processing chamber having a workpiece support surface configured to support a workpiece during processing of the workpiece, the workpiece support including an electrostatic chuck. The electrostatic chuck can include one or more clamping electrodes defining a clamping layer; one or more heating electrodes defining a heating layer; a thermal control system; and a sealing band surrounding an outer perimeter of the electrostatic chuck, the sealing band having a width of at least about 3 mm up to about 10 mm.

In some embodiments, the one or more clamping electrodes comprise a first clamping electrode and a second clamping electrode.

In some embodiments, the thermal control system including one or more flow channels for circulating a thermal exchange fluid or a thermal exchange gas.

In some embodiments, the thermal exchange gas comprises helium gas.

In some embodiments, the flow channels are interconnected to a first zone of release apertures, a second zone of release apertures, a third zone of release apertures, and a fourth zone of release apertures.

In some embodiments, the first zone of release apertures is located innermost radially, wherein the second zone of release apertures is located radially outward from the first zone of release apertures, wherein the third zone of release apertures is located radially outward from the second zone of release apertures and radially inward from the fourth zone of release apertures.

In some embodiments, the second zone of release apertures includes more apertures than the first zone of release apertures, wherein the third zone of release apertures includes more apertures than the second zone of release apertures, wherein the fourth zone of release apertures includes more release apertures than the third zone of release apertures.

In some embodiments, the sealing band is configured to seal the workpiece support surface, such that thermal exchange gas is not capable of leaking around an edge of the workpiece.

Another example embodiment of the present disclosure is directed to a system for processing workpiece. The system includes a processing chamber, the processing chamber configured to perform at least one treatment process on a workpiece. The system includes a workpiece support disposed in the processing chamber. The workpiece support includes one or more clamping electrodes defining a clamping layer, one or more heating electrodes defining a heating layer, a thermal control system including one or more flow channels for circulating a thermal exchange fluid or a thermal exchange gas, wherein the flow channels are interconnected to a first zone of release apertures, a second zone of release apertures, a third zone of release apertures, and a fourth zone of release apertures, and a sealing band surrounding an outer perimeter of the electrostatic chuck, the sealing band having a width of at least about 3 mm to about 10 mm. The system includes a controller, the controller configured to adjust one or more of (i), (ii), or (iii) in order to adjust workpiece uniformity: (i) a power output from one or more power sources to the one or more clamping electrodes and/or the one or more heating electrodes; (ii) a power source to the one or more clamping electrodes and/or the one or more heating electrodes; or (iii) a flow rate of the thermal exchange fluid or the thermal exchange gas in the thermal control system.

Another example embodiment of the present disclosure is directed to an electrostatic chuck. The electrostatic chuck includes a workpiece support surface configured to support a workpiece during processing. The electrostatic chuck includes a pixelated array of a plurality of micro-electrodes. The electrostatic chuck includes at least one RF bias source coupled to each of the plurality of micro-electrode. The electrostatic chuck includes a clamping power source configured to provide clamping power to each of the plurality of micro-electrodes so that each of the plurality of micro-electrodes is configured to act as a clamping electrode for the workpiece. The electrostatic chuck includes a controller configured to control the at least one RF bias source to independently adjust one or more RF parameters of RF bias power to one of the plurality of micro-electrodes relative to at least one other of the plurality of micro-electrodes.

In some embodiments, the RF bias source comprises a plurality of RF bias sources, each of the plurality of RF bias sources coupled to at least one of the plurality of micro-electrodes.

In some embodiments, the one or more RF parameters comprise one or more of RF power, RF frequency, or RF phase.

In some embodiments, the system further includes a baseplate disposed beneath the plurality of micro-electrodes in the electrostatic chuck.

In some embodiments, the RF bias source is configured to provide RF bias power to the baseplate.

In some embodiments, the clamping power source is configured to provide a plurality of different DC voltages to each of the plurality of micro-electrodes.

In some embodiments, the clamping power source comprises a DC power source, the DC power source coupled to at least one of the micro-electrodes via a switching element.

In some embodiments, the controller is configured to control the switching element using a pulse width modulation to adjust a voltage applied to the at least one micro-electrode coupled to the switching element.

In some embodiments, the RF bias source comprises the clamping power source, the clamping power source comprising a DC power source coupled to at least one of the micro-electrodes via a switching element, the controller configured to apply RF bias to at least one of the micro-electrodes by controlling the switching element using pulse width modulation.

In some embodiments, the controller is configured to apply RF bias to at least one of the micro-electrodes by controlling the switching element using pulse width modulation at a frequency in a range of about 1 kHz to 2 MHz.

In some embodiments, the clamping power source comprising a single DC power source coupled to each of the plurality of micro-electrodes via a switching network, the controller configured to selectively control one or more switching in the switching network to selectively apply clamping power and/or RF bias to one or more of the plurality of micro-electrodes.

In some embodiments, each of the plurality of micro-electrodes are embedded in a ceramic puck.

In some embodiments, the electrostatic chuck comprises a dielectric layer disposed between the plurality of micro-electrodes and the workpiece.

Another example embodiment of the present disclosure is directed to a workpiece processing apparatus. The apparatus includes a processing chamber. The apparatus includes a workpiece support comprising an electrostatic chuck including a workpiece support surface disposed in the processing chamber. The electrostatic chuck includes a pixelated array of a plurality of micro-electrodes; at least one RF bias source coupled to each of the plurality of micro-electrodes; a clamping power source configured to provide clamping power to each of the plurality of micro-electrodes so that each of the plurality of micro-electrodes is configured to act as a clamping electrode for the workpiece; and a controller configured to control the at least one RF bias source to independently adjust one or more RF parameters of RF bias power to one of the plurality of micro-electrodes relative to at least one other of the plurality of micro-electrodes.

In some embodiments, the RF bias source comprises a plurality of RF bias sources, each of the plurality of RF bias sources coupled to at least one of the plurality of micro-electrodes.

In some embodiments. the one or more RF parameters comprise one or more of RF power, RF frequency, or RF phase.

In some embodiments, the apparatus further comprises a baseplate disposed beneath the plurality of micro-electrodes in the electrostatic chuck.

In some embodiments, the RF bias source is configured to provide RF bias power to the baseplate.

In some embodiments, the clamping power source is configured to provide a plurality of different DC voltages to each of the plurality of micro-electrodes.

In some embodiments, the clamping power source comprises a DC power source, the DC power source coupled to at least one of the micro-electrodes via a switching element.

In some embodiments, the controller is configured to control the switching element using pulse width modulation to adjust a voltage applied to the at least one micro-electrode coupled to the switching element.

In some embodiments, the RF bias source comprises the clamping power source, the clamping power source comprising a DC power source coupled to at least one of the micro-electrodes via a switching element, the controller configured to apply RF bias to at least one of the micro-electrodes by controlling the switching element using pulse width modulation.

In some embodiments, the controller is configured to apply RF bias to at least one of the micro-electrodes by controlling the switching element using pulse width modulation at a frequency in a range of about 1 kHz to 2 MHz.

In some embodiments, the clamping power source comprising a single DC power source coupled to each of the plurality of micro-electrodes via a switching network, the controller configured to selectively control one or more switching in the switching network to selectively apply clamping power and/or RF bias to one or more of the plurality of micro-electrodes.

In some embodiments, each of the plurality of micro-electrodes are embedded in a ceramic puck.

In some embodiments, the electrostatic chuck includes a dielectric layer disposed between the plurality of micro-electrodes and the workpiece.

While the present subject matter has been described in detail with respect to specific example embodiments thereof, it will be appreciated that those skilled in the art, upon attaining an understanding of the foregoing may readily produce alterations to, variations of, and equivalents to such embodiments. Accordingly, the scope of the present disclosure is by way of example rather than by way of limitation, and the subject disclosure does not preclude inclusion of such modifications, variations and/or additions to the present subject matter as would be readily apparent to one of ordinary skill in the art.

What is claimed is:

1. A workpiece processing apparatus, comprising:
- a processing chamber;
- a workpiece support disposed in the processing chamber, the workpiece support including an electrostatic chuck, the electrostatic chuck comprising:
- a workpiece support surface configured to support a workpiece during processing;
- one or more clamping electrodes defining a clamping layer;
- one or more heating electrodes defining a heating layer;
- a thermal control system; and
- a sealing band surrounding an outer perimeter of the electrostatic chuck including at least a portion of the workpiece support surface, the sealing band having a width greater than about 3 millimeters (mm) up to about 10 mm.

2. The workpiece processing apparatus of claim **1**, wherein the clamping electrodes are connected to one or more of a DC power source, AC power source, or an RF power source.

3. The workpiece processing apparatus of claim **1**, wherein the one or more clamping electrodes comprise a first clamping electrode and a second clamping electrode.

4. The workpiece processing apparatus of claim **3**, wherein the first clamping electrode is coupled to a negative DC voltage, and the second clamping electrode is coupled to a positive DC voltage.

5. The workpiece processing apparatus of claim **1**, wherein the thermal control system comprises one or more flow channels for circulating a thermal exchange fluid or a thermal exchange gas.

6. The workpiece processing apparatus of claim **5**, wherein the thermal exchange gas comprises helium gas.

7. The workpiece processing apparatus of claim **5**, wherein the flow channels are interconnected to a first zone of release apertures, a second zone of release apertures, a third zone of release apertures, and a fourth zone of release apertures.

8. The workpiece processing apparatus of claim **7**, wherein the first zone of release apertures is located innermost radially, wherein the second zone of release apertures is located radially outward from the first zone of release apertures, wherein the third zone of release apertures is located radially outward from the second zone of release apertures and radially inward from the fourth zone of release apertures.

9. The workpiece processing apparatus of claim **7**, wherein the second zone of release apertures includes more apertures than the first zone of release apertures, wherein the third zone of release apertures includes more apertures than the second zone of release apertures, wherein the fourth zone of release apertures includes more release apertures than the third zone of release apertures.

10. The workpiece processing apparatus of claim **5**, wherein the sealing band is configured to seal the workpiece support surface, such that thermal exchange gas is not capable of leaking around an edge of the workpiece.

11. The workpiece processing apparatus of claim **1**, wherein the electrostatic chuck defines a first outer boundary and the clamping layer defines a second outer boundary, wherein a first distance D1 between the first outer boundary and the second outer boundary is greater than a second distance D2 defined between one or more turns of the first electrode or the second electrode in the clamping layer, wherein D1 is greater than about 2 millimeters (mm).

12. A workpiece processing apparatus, comprising:
- a processing chamber;
- a workpiece support disposed in the processing chamber, the workpiece support including an electrostatic chuck, the electrostatic chuck comprising:
- a workpiece support surface configured to support a workpiece during processing;

a pixelated array of a plurality of micro-electrodes;

at least one RF bias source coupled to each of the plurality of micro-electrodes;

a clamping power source configured to provide clamping power to each of the plurality of micro-electrodes so that each of the plurality of micro-electrodes is configured to act as a clamping electrode for the workpiece; and

a controller configured to control the at least one RF bias source to independently adjust one or more RF parameters of RF bias power to one of the plurality of micro-electrodes relative to at least one other of the plurality of micro-electrodes.

13. The workpiece processing apparatus of claim **12**, wherein the RF bias source comprises a plurality of RF bias sources, each of the plurality of RF bias sources coupled to at least one of the plurality of micro-electrodes.

14. The workpiece processing apparatus of claim **12**, wherein the one or more RF parameters comprise one or more of RF power, RF frequency, or RF phase.

15. The workpiece processing apparatus of claim **12**, further comprising a baseplate disposed beneath the plurality of micro-electrodes in the electrostatic chuck.

16. The workpiece processing apparatus of claim **15**, wherein the RF bias source is configured to provide RF bias power to the baseplate.

17. The workpiece processing apparatus of claim **12**, wherein the clamping power source is configured to provide a plurality of different DC voltages to each of the plurality of micro-electrodes.

18. The workpiece processing apparatus of claim **12**, wherein the clamping power source comprises a DC power source, the DC power source coupled to at least one of the micro-electrodes via a switching element.

19. The workpiece processing apparatus of claim **18**, wherein the controller is configured to control the switching element using a pulse width modulation to adjust a voltage applied to the at least one micro-electrode coupled to the switching element.

20. The workpiece processing apparatus of claim **12**, wherein the RF bias source comprises the clamping power source, the clamping power source comprising a DC power source coupled to at least one of the micro-electrodes via a switching element, the controller configured to apply RF bias to at least one of the micro-electrodes by controlling the switching element using pulse width modulation.

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